DELHI COLLEGE OF ENGINEERING

LIBRARY

CLASS NO 621.3

BOOK NO W AL

ACCESSION NO 7058

DATE DUE

For each day's delay after the due date a fine of 3 P per Vol shall be charged for the first week, and 25 P per Vol. per day for subsequent days.

Borrower's No	Date Due	Borrower's No.	Date Due

PHOTOELECTRIC CELL APPLICATIONS

A PRACTICAL BOOK
DESCRIBING THE USES OF PHOTOELECTRIC CELLS
IN TELEVISION, TALKING PICTURES,
ELECTRICAL ALARMS, COUNTING DEVICES, ETC.

BY

R. C. WALKER, B.Sc. (Lond.)

AND

T. M. C. LANCE, Associate I.R.E.

LONDON
SIR ISAAC PITMAN & SONS, LTD.
1933

SIR ISAAC PITMAN & SONS, LTD
PARKER STREET, KINGSWAY, LONDON, W C 2
THE PITMAN PRESS, BATH
THE RIALTO, COLLINS STREET, MELBOURNE
2 WEST 45TH STREET, NEW YORK
SIR ISAAC PITMAN & SONS (CANADA), LTD
70 BOND STREET, TORONTO

PRINTED IN GREAT BRITAIN
AT THE PITMAN PRESS, BATH

PREFACE

In the following pages, we have endeavoured to describe some typical examples of the many practical applications of the photoelectric cell. The average engineer, manufacturer, and industrialist is generally fully occupied with details of his own particular requirements, and has neither the time nor the opportunity to study the physical laws involved in the operation of light sensitive devices. He is frequently prepared to dismiss the "Electric Eye" as an interesting novelty. Yet the photocell partnered by the thermionic valve or the grid glow tube will undoubtedly play a great part in the future industrial development.

Throughout the book, we have kept before us one ideal, namely, simplicity of treatment, with the hope that our descriptions may prove helpful to the practical man and suggest to him means of attacking some of his problems with a new weapon. On the other hand, we trust that those who have a wider knowledge of the subject will not be too harsh in their criticism of our intentional omission of all mathematical, and many theoretical considerations which some problems may involve.

The physics of photoelectric cells has been condensed into one short chapter as the subject has already been dealt with elsewhere authoritatively by others, notably in "Photoelectric Cells" by Campbell & Ritchie (Pitman).

We have dealt here exclusively with the alkali metal cells, chiefly because we have most acquaintance with them and prefer to record our own experience rather than the hearsay evidence of others. There is no reason, however, in many cases why other types of light sensitive devices could not be equally well employed with some modification of the circuits given.

Permission to reproduce photographs of installations has been withheld in some instances, for very good reasons, and in such cases it is only possible to give brief outlines of these applications, but we are greatly indebted to the many firms whose names are mentioned herein for their kind co-operation in supplying photographs, drawings, and information. In particular, our appreciation is due to the Directors of the General Electric Co., Ltd., and to the Director of the Research Laboratories for permission to publish information connected with our normal duties, and to Dr. N. R. Campbell for his helpful criticism and advice.

A portion of the book has already appeared in serial form in the *Wireless World*, and permission to reproduce here is duly acknowledged.

R.C.W.
T.M.C.L.

CONTENTS

PAGE
PREFACE v

CHAPTER I

CHARACTERISTICS OF CELLS 1
Historical—Vacuum cells—Gas-filled cells—Time lag

CHAPTER II

CIRCUIT DIAGRAMS 17
Galvanometer circuits—Grid glow tube—Thermionic valves—The Gas-filled relay—Special cases—Relays—Light units—Accessories

CHAPTER III

COUNTING AND TIMING GEAR 39
Typical installations—One-way recording—Multiple recording—Timing of races—Miscellaneous cases

CHAPTER IV

ALARMS, INDICATORS, AND SAFETY DEVICES 49
Safety circuits—Burglar alarms—Smoke and gas detectors—Machine controls—Gauges—Miscellaneous

CHAPTER V

ADVERTISING 70
Illuminated signs—Shop-window displays—Novelties

CHAPTER VI

TALKING FILMS 85
Types of sound on film record—The optical system—Photo-cell coupling—Frequency characteristics

CHAPTER VII

PHOTO TELEGRAPHY 114
Principles involved—Fulton transmitter—Belin system—Bartlane system—Recent developments

CHAPTER VIII

PAGE
TELEVISION 136
Fundamental principles—Bell and Baird transmitters—Colour television—Future developments

CHAPTER IX

SCIENTIFIC INSTRUMENTS 153
Recording microphotometer — Density meter — Photometry — Lamps and colour temperature—Ultra violet ray measurements—Colour matching instruments

CHAPTER X

MISCELLANEOUS APPLICATIONS 177
Additional circuits—Devices for increasing sensitivity, etc.

INDEX 191

INSET . . . . *facing* 173

PHOTOELECTRIC CELL APPLICATIONS

CHAPTER I

CHARACTERISTICS OF CELLS

Introduction.

WHILST it has been stated that no attempt will be made here to deal completely with the theoretical aspect of photoelectricity, it cannot be assumed that all those interested in the practical applications of photocells will be familiar with their fundamental properties. It is obvious, therefore, that it would be a serious omission to neglect some reference to their characteristics.

For this reason then the first chapter is devoted to a simple description of the photoelectric effect, its discovery and development. Those features of the various types of cells here discussed have been selected to give a clear insight to the performance of photocells in practical applications. There are, of course, many other interesting features and developments that will be omitted completely in order to prevent the practical minded becoming confused by too many details.

Historical.

The photoelectric effect was discovered by Hertz in 1887 during his investigations on wireless waves, and as it was afterwards fully described by the German chemist, Hallwachs, it became known subsequently as the "Hallwachs" effect. It is frequently described in text books on physics under this title. Hallwachs observed that an insulated negatively charged zinc plate rapidly lost its charge if illuminated by a carbon arc, but retained its charge if a sheet of glass was interposed between the arc and the metal plate. The discharge is due to the emission of negative particles set free by the ultra violet rays from the arc. The current produced as a result of the emission of these particles is called the photoelectric current.

Hallwachs' experiment can be easily demonstrated with the simple apparatus shown in Fig. 1. An insulated zinc plate, negatively charged, is shown connected to an electroscope, the leaves of which will remain diverged as long as the plate retains its charge. A few inches of burning magnesium wire held in front of the wire gauze cause the leaves of the electroscope to collapse, indicating the loss of the charge which had been imparted to the plate. If the experiment is repeated with a piece of ordinary plate-glass between the burning magnesium ribbon and the apparatus, the effect is nullified—the charge does not escape. The zinc plate must be brightly polished to illustrate the effect properly as it will be found that the loss of charge does not take place if the surface becomes tarnished.

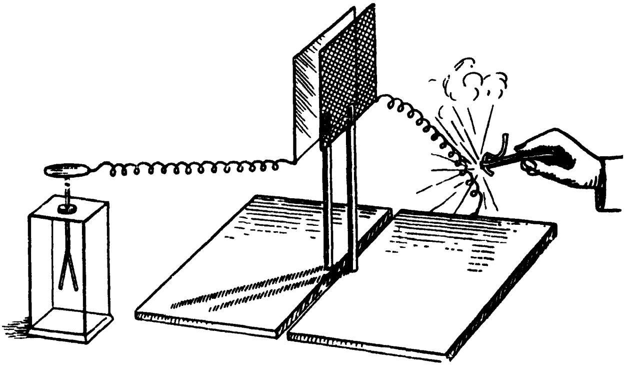


FIG. 1. HALLWACHS EFFECT

With the development of the theory of atomic physics which followed Hallwachs' experiments, and the researches of Sir J. J. Thomson and others, an explanation of these facts was soon forthcoming. We know now that the ultra violet rays from the burning magnesium wire liberate electrons or negatively charged particles from the plate thus reducing the negative charge imparted to the plate. Glass absorbs ultra violet rays and this prevents them from reaching the plate. Under these conditions the zinc plate retains its charge.

Modern Atomic Theory.

The present-day theory of atomic structure assumes that the atoms of all the elements consist of systems of two kinds of smaller particles, protons or elements of positive electricity and electrons or elements of negative electricity. Some of the electrons and the protons form a central nucleus which is the smaller but more massive portion of the atom. The remaining electrons circulate around the central mass, the obvious analogy to the planets circulating round the sun in the solar system having given them the name of planetary electrons. In an atom the total number of protons is equal to the total number of electrons. The planetary electrons, though free to move in their orbits, are closely restrained when they approach the boundary of the atomic structure. If, however, energy is communicated to them from outside one or more of these planetary electrons may approach the boundary with sufficient energy to break loose, leaving the remainder of the atom with an excess of protons over electrons and, consequently, a positive charge. Such a positively charged particle is known as a positive ion.

We can imagine the planetary electrons to be marbles rolling about in a soup plate. They are free to move about at the bottom of the plate but cannot get out of the plate unless they have sufficient speed to roll up the side and fall over the edge. Light falling on the surface of certain metals imparts the required energy to the planetary electrons of the atoms and in consequence some of them escape from the parent atom at the surface boundary of the metal and pass into the surrounding space. The liberation of electrons from the atom and their subsequent passage through space constitutes the photoelectric current.

The identity of the photoelectrons with cathode rays has been definitely established, and the photoelectric effect has been found to be a perfectly general one exhibited by all elements for radiant energy of suitable frequency. For instance, if we consider radiations of the highest frequency, i.e. X-rays or γ-rays, a photo emission is always produced by these radiations[1] whenever they fall upon the surface of any metal. On the other hand, waves of the lowest frequency, i.e. wireless waves, are incapable of producing an electron emission from the surface of any substance. Between these extreme limits of high and low frequency, there is a comparatively narrow band of frequencies which have the power of exciting the sense of sight, and radiations in this band convey to the human brain, through the optic nerve, the impression of light and colour. This band of frequencies constitutes the visible spectrum, and the wavelengths range between 7,500 A.U., for deep red light, and 4,000 A.U. for deep blue light. Immediately above and below this band lie respectively the *infra* red and the *ultra* violet radiations of which considerable use is made in some photoelectric applications.

---

[1] In terms of wavelength, to which the frequency is inversely proportional, the extremes are of the order of 10^{-9} cm. for γ-rays to 10^{6} cm. in the case of wireless waves.

Three units are in common use for specifying wavelengths of radiation, i.e.—

(1) The Angström Unit (A.U.) = 10^{-10} metre.
(2) The micron ($1\ \mu$) = 10^{-3} mm.
(3) The millimicron ($1\ m\mu$) = 10^{-6} mm.

In the brief description of Hallwachs' experiments with which this chapter opened, mention was made of the fact that it was the ultra violet component of the light from the burning magnesium ribbon which produced the photoelectric effect, for if this radiation was absorbed by a piece of plate-glass, the effect was nullified. This is because the photoelectric sensitivity of the zinc cathode shows the greatest response to ultra violet radiation. Elster and Geitel found that some elements were sensitive to visible light. Only seven elements show any appreciable photoelectric emission for radiation within the visible spectrum, viz. lithium, sodium, potassium, rubidium, caesium, strontium and barium, and these metals have a peak sensitivity at some wavelength in the visible range.

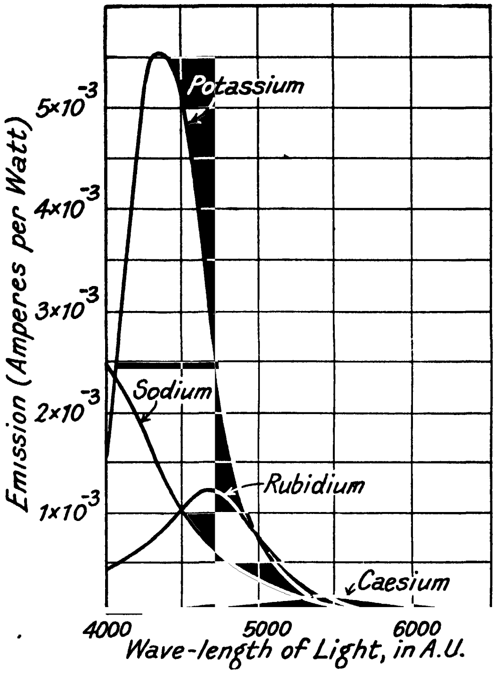


FIG. 2. AVERAGE EMISSION CURVES FOR ALKALI METALS (THICK FILMS)

The earlier forms of photocells contained, therefore, one of these metals as the light sensitive surface. Subsequent developments and research have shown that the most satisfactory cells are those which have cathodes consisting of very thin alkali metal coatings on a suitably prepared base, but we will revert to this point later on and deal with the simpler form of cathode first.

It has been mentioned that the alkali metals are intensely active chemically, and unite with oxygen very vigorously, so that the preparation of a metallic surface of these metals is in itself a matter of some considerable difficulty, and can obviously only be managed and maintained in a vacuum or an inert atmosphere.

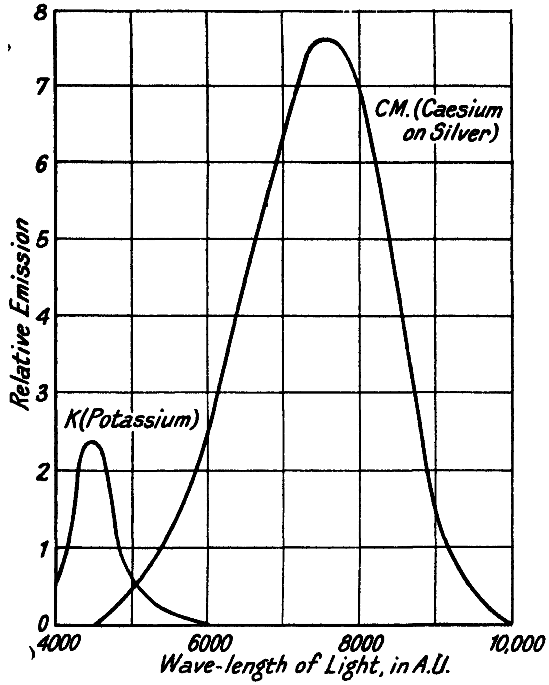


FIG. 3. RELATIVE EMISSION OF CAESIUM ON SILVER (THIN FILM) AND POTASSIUM (THICK FILM) CATHODES

A photocell consists then essentially of a cathode composed of one of the alkali metals or a thin film of one of such metals on a suitably prepared base (the cathode being connected externally to a negative potential) and another metal electrode—the anode—which may take any form such as a ring of wire, or a gauze, or grid of wires, connected externally to a positive potential, the two electrodes being enclosed in an evacuated vessel, or one filled with an inert gas.

For the detection of ultra violet radiation practically any metal will give a photoelectric response. Lithium, sodium, platinum, and aluminium have been employed, but cadmium is more generally used. In the visible range of the spectrum, potassium sensitized by a discharge in hydrogen by the well-known Elster and Geitel process until quite recently formed the cathode of most photocells.

The general outline of the sensitivity wavelength curve for the visible spectrum is shown in Fig. 2.

Recent developments have shown that much more satisfactory cells can be produced with cathodes consisting of a very thin layer, probably of monatomic dimensions, of an alkali metal deposited on a support consisting of oxidized copper or silver. Various combinations have been investigated, with the result that so far the caesium-on-silver oxide cathode has proved to be the most efficient for general purposes. It is essential, therefore, to distinguish the older type "mass" layer cathode from the more modern "thin" film cathode. In general, the thin film cathodes have peak responses nearer the red

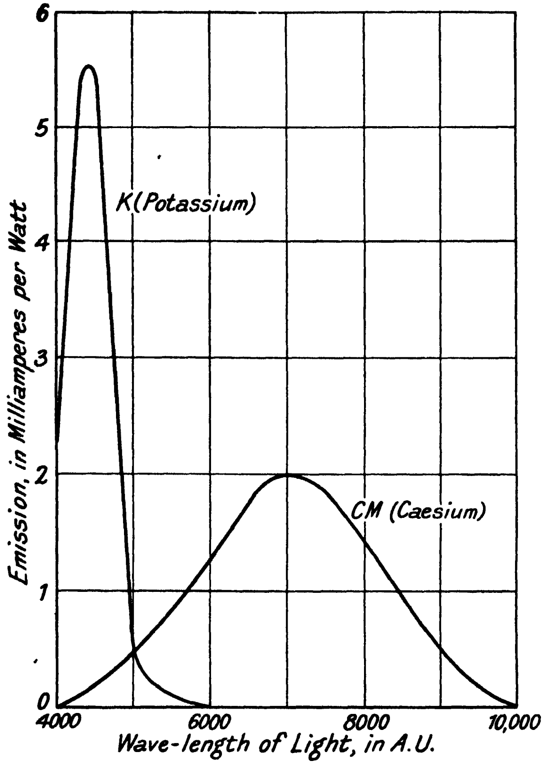


FIG. 4. RELATIVE RESPONSE FOR UNIFORM DISTRIBUTION OF ENERGY IN INCIDENT RADIATION

end of the spectrum than the "mass" layer cathodes, and in consequence their point of maximum sensitivity more nearly approaches the peak of the energy emission curve of an incandescent body, in most cases a gas-filled lamp at a filament temperature of about 2,700° K. Hence their particular utility and sensitivity to most forms of artificial illumination.

In describing cells manufactured in this country by the General Electric Company, the thin film cathodes are distinguished by the letter "M" which occurs in the type index, viz. C.M.G.8. This notation is used throughout this book to indicate the cathode material, cathode form, gas-filling and type of cell wherever Osram cells are used.

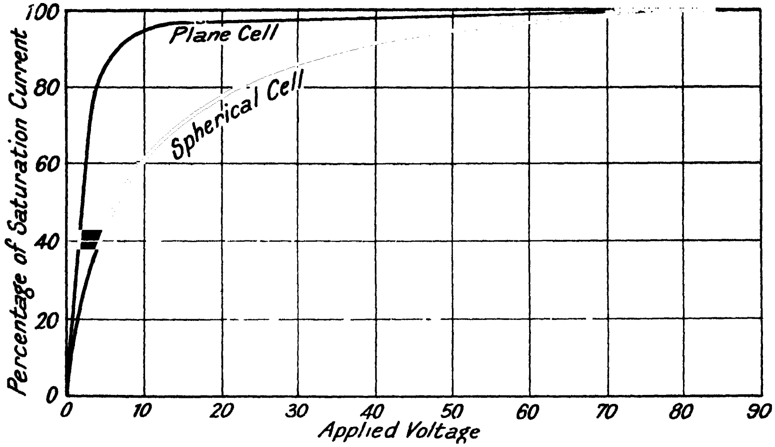


FIG. 5. VACUUM CELL CHARACTERISTICS

Except for a few special purposes, the thin film cathode cell is much to be preferred, and the early mass types are now nearly obsolete. Fig. 3 illustrates this point, as it represents the response of the C.M. type compared with the potassium type, to radiation from a gas-filled electric lamp, the source of illumination most frequently used. It should be remembered, however, that the "mass" cathode cells have advantages under certain circumstances. Fig. 4 illustrates the response of the two types of cathode to radiant energy which is uniformly distributed throughout the range of wavelengths, shown on the horizontal axis of co-ordinates. Care should be taken to distinguish exactly the different conditions under which the two curves shown in Figs. 3 and 4 are true. It is clear that if the light to be detected is blue or violet, then the potassium is more sensitive.

The Vacuum Cell.

Theoretically the simplest form of photocell is that in which the electrodes are enclosed in a vessel free from gas. With a given amount of luminous energy incident on the cathode, the vacuum cell will show a gradually increasing current with increasing anode voltage up to about 20 volts which is sufficient to produce approximate saturation. Fig. 5 shows the current voltage characteristics for vacuum cells with different electrode construction. Actually, complete saturation is not attained even at 100 volts for reasons which need not be discussed here. The photoelectric current measured under such conditions is known as the "primary emission" and is a measure of the relative sensitivity of the cathode under consideration.' The sensitivity of various cathodes is shown in Fig. 6, and is usually specified in microamperes per lumen[1] ,

Designation of Cathode	Nature of Cathode	Emission (Microamperes per Lumen)
CM	A film of caesium on silver	24·0
RM	A film of rubidium on silver	5·0
KM	A film of potassium on silver or copper	1·0
KV	Sensitized potassium in vacuous cells	0·5
KG	Sensitized potassium in gas-filled cells	1·7
N	Sensitized sodium	0·6
D	Cadmium	less than 0·1

FIG. 6. RELATIVE SENSITIVITY OF CELLS

In calculating the amount of light falling on the cathode of a photocell, it must be remembered that the intensity of illumination is inversely proportional to the square of the distance, if the dimensions of the source compared with the distance from it are small. Hence, a surface of area S sq. cms. distant r cms. from a source emitting L lumens receives $\frac{SL}{4\pi r^2}$ lumens, assuming uniform radiation in all directions.

---

[1] The lumen is the unit of radiated luminous energy, or perhaps more simply—unit quantity of light. If we imagine a source of 1 candle-power placed at the centre of a sphere of 1 unit radius, then the amount of light received on 1 sq. unit area of surface of the sphere is 1 lumen, assuming uniform radiation in all directions. Hence, the radiation from a source of 1 candle-power is 4π lumens. The foot candle is the unit of intensity of illumination, and is the intensity of illumination of a surface at a distance of 1 ft. from a source of 1 candle-power. Hence foot candles = lumens per sq. foot.

Another unit common in Continental countries is the lux or metre candle, being the illumination of a surface at a distance of 1 metre from a source of 1 Hefner candle-power (0·9 standard international candle-power).

In calculating the current to be expected from a photocell exposed directly to the lamp, the surface S is that of the cathode or of the window through which light is admitted to the cathode—whichever is the smaller. If the light is concentrated on to the cathode by means of a lens, S is approximately the area of the lens.

As mentioned previously, approximate saturation in a vacuum cell occurs at about 20 volts. This is the condition under which nearly all the electrons emitted from the cathode reach the anode. Further increase of applied voltage results in very little increase in photoelectric current. High voltages should not be used with vacuum cells, as no advantage is thereby gained, and leakage current under such conditions becomes of increasing importance. In order to minimize the effect of leakage current, a vacuum cell should be provided with an internal guard ring. Fig. 7 shows a typical vacuum cell with internal guard ring consisting of a metallic surface deposited on the glass between, but insulated from, both electrodes and connected to an external side terminal. Leakage current tending to pass between the electrodes can then be shunted through the guard ring terminal, and so avoid passing through the measuring instrument in circuit. If necessary, an external guard ring can be improvised by wrapping a few turns of bare copper wire round the neck of the bulb to reduce external leakage.

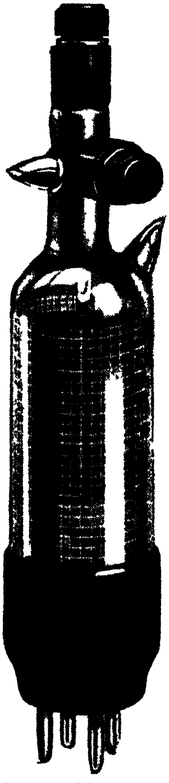


FIG 7 VACUUM PHOTOCELL

The chief characteristic of the vacuum cell is its constancy and the linear relationship between photoelectric current and incident radiation. Increasing the light on the cell will result in a proportionate increase in photoelectric current. The vacuum cell is therefore an instrument of precision, and should always be used where numerical records are required and where constancy of reproduction is of first importance, even though some sacrifice in sensitivity is incurred.

Gas-filled Cells.

In cases where the detection of light only is the chief requirement, it is necessary to obtain as great a sensitivity as possible. This can be secured by filling the cell with an inert gas, usually helium or argon, and applying higher voltages between the electrodes.

It is interesting to consider in more detail some of the effects of gas filling. If the applied voltage is gradually increased, the velocity at which the electrons are travelling at a short distance from the cathode is approximately proportional to the square root of the applied potential. Hence, at first, when the applied voltage is low, the velocity of the photoelectrons is small, and in their passage toward the anode they collide with the atoms of the gas and merely rebound after collision. As the applied voltage is raised, the velocity of the photoelectrons increases and the collisions become more violent. Above a certain velocity sufficient energy is absorbed by the atoms of the gas in these collisions, to set free one or more of their planetary electrons, leaving behind the positive ion. The secondary electrons so produced join in the main stream of photoelectrons, and these in their turn produce others, and so the effect becomes cumulative. Hence the total number of electrons which reach the anode, and which constitutes the photoelectric current, becomes very much increased.

This process by which the original current becomes magnified is known as "ionization by collision." The positive ions formed by the collisions between the primary electrons and the atoms of the gas, are driven back on the cathode and produce a further electron emission, the effect being equivalent to an increase in illumination. It is clear then that if the number of positive ions driven back on the cathode is sufficiently large, they should give rise to an emission which is as great as that produced by the original light incident on the cathode, and the current should continue to flow even when the light is cut off. Actually, this is what does happen when a high voltage is applied to a photocell and is termed the "glow discharge." It is visible as a pale luminous glow within the cell, and is accompanied by a sudden and large increase in current.

Under these conditions the photocell is no longer sensitive to light, and the current will continue after the light has been cut off. The passage of the glow discharge alters somewhat the characteristics of the cell and, if allowed to continue for any length of time, will invariably destroy the light sensitive properties of the cathode. The length of time for which the discharge can be allowed to pass without damaging the cell depends upon the type of cell and its electrode construction. Incidentally, it should be mentioned, that a photocell should never be connected to a source of electric supply without having a protective resistance of not less than 10,000 and, preferably, of 250,000 ohms in circuit to limit this current. Actually, if the glow discharge is passed momentarily in the potassium cell, an increase in sensitivity results. This fact has been used in order to secure the greatest possible output from this particular type of cell by adopting the procedure of allowing the greatest available light to fall on the cathode, increasing the voltage until the glow discharge passes, reducing it until it ceases, and then again increasing until it is just below the point at which the glow originally started. The continuance of the discharge will, as in the case of all other cells, eventually destroy the cathode.

It is important to note that the voltage at which the glow discharge passes depends on the amount of light on the cathode, and is lower the larger the amount of light. Hence, care should be taken to see that when connected to a source of electric supply a gas-filled cell is not exposed to a sudden increase in illumination, which may cause the glow discharge to pass unnoticed.

The various phenomena taking place within a gas-filled cell can be appreciated by considering the characteristic curves shown in Fig. 8. These are actually taken with one of the older potassium types of cell, and show the relation existing between applied voltage and current for different illuminations. Ordinates are to a logarithmic scale, and the light flux indicated against each curve refers to total visible radiation actually incident on the cathode. It will be seen that up to a certain point all the curves are approximately parallel, but that, subsequently, they differ widely, and the increase of current with voltage rise is very rapid. Most cells of modern manufacture have glow potentials lower than those shown in the illustration, but the curves suffice to show the general behaviour of a gas-filled cell. The curves corresponding to various illuminations end abruptly at points marked X, which indicate the termination of the flow of steady current and the beginning of the glow discharge E_1. These points all lie on what is known as the "limiting curve," shown continuous in its upper and lower portions and dotted in the middle portion. It will be seen to consist of four distinct parts—

(*a*) An initial vertical line AX on which no points are marked and which corresponds to low illuminations.

(*b*) An almost flat portion where a "space" charge of positive ions collects in front of the cathode, producing an increase in field and causing the limiting current to vary very slightly with the light.

(*c*) A vertical dotted portion *CD* where the limiting current increases enormously with very small change of illumination.

(*d*) A continuous curve *DE* bending over towards the horizontal,

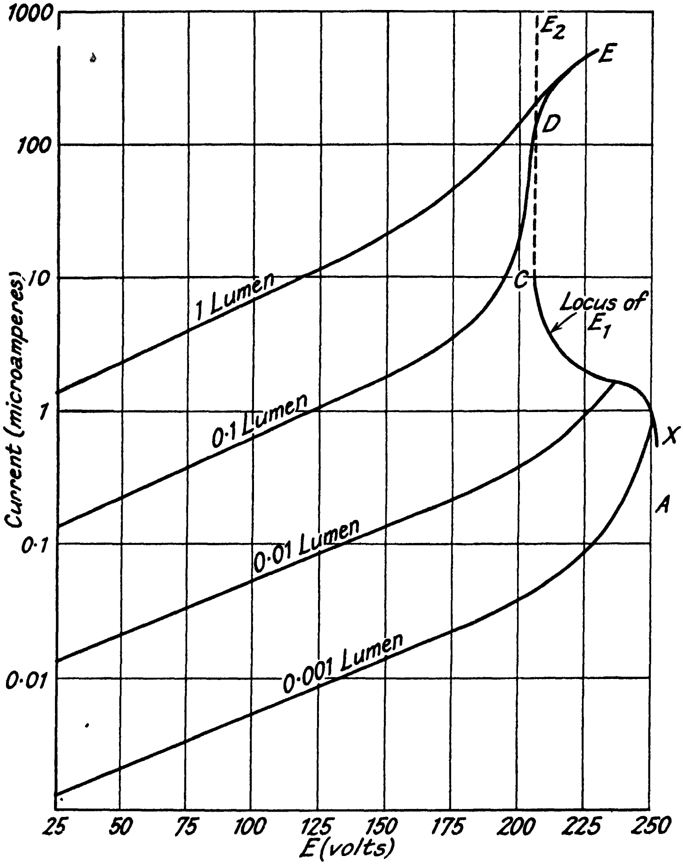


Fig. 8. Characteristic Curves of Gas-filled Cells

indicating that owing to recombination of ions, the current does not increase indefinitely.

These curves show that the behaviour of the gas-filled cells at relatively high voltages depends on the amount of light available. If this is comparatively small, as illustrated in the two lower curves, the current will at the point *X* suddenly increase to a value indicated by the corresponding ordinate on the upper continuous curve. The current is now independent of the light, and does not stop when the light is removed. If the voltage is now reduced the current will fall along the upper part of the limiting curve until the dotted line representing the stopping potential E_2 is reached. The glow discharge then ceases, and the current falls back to the value shown on the original characteristic. When the light is comparatively large—as shown by the top of the diagram—the current again becomes independent of the light when the glow discharge passes, but there is no sudden and great increase in current. In this case the existence of the glow discharge can be detected by switching off the light and observing whether the current ceases. It is obvious, therefore, that high magnifications can only be obtained with low illuminations.

It is evident that the maximum current is obtained when the cell operates just below its glowing potential, and that if the light is relatively large, the maximum permissible voltage will be that of the stopping potential E_2. It must be remembered that these are typical characteristics, and that the values of voltage vary from cell to cell. The figures given, therefore, only apply to an individual cell.

The primary photoelectric current in different cells will probably be different, and the starting and stopping potentials vary between fairly wide limits. Also the general form of the limiting curve is subject to some variation.

To safeguard users it is now the practice to mark photocells which are intended for industrial use as opposed to laboratory applications, with the maximum voltage that can be applied at a specified illumination without fear of damage from the glow discharge. At the same time a certain emission with this voltage is guaranteed, so by increasing the efficiency of their cells, the manufacturers can arrange that the voltage stated is sufficiently far removed from the stopping potential to avoid all risk of a discharge during normal operating conditions.

Cathode Construction.

All the qualitative statements hitherto made apply with some modification to all gas-filled cells. When cells of a similar type are compared, the differences are in general merely absolute values of voltage; one set of curves can be made to fit very nearly any cell by expansion or contraction of the scale of voltages. Among cells of different types far greater changes are found. As regards form, they may be divided roughly into two classes—

(*a*) Those in which the areas of the electrodes are widely different.

(*b*) Those in which the electrodes approximate to parallel planes of the same area.

In type (*a*) the sparking voltage varies much more with the illumination than in type (*b*), and the rate of increase of magnification with voltage near the sparking voltage is greater. On the other hand, the maximum magnification with small illumination is rather greater in type (*a*). On the whole, type (*a*) is preferable for very small illuminations, and type (*b*) for moderate illuminations.

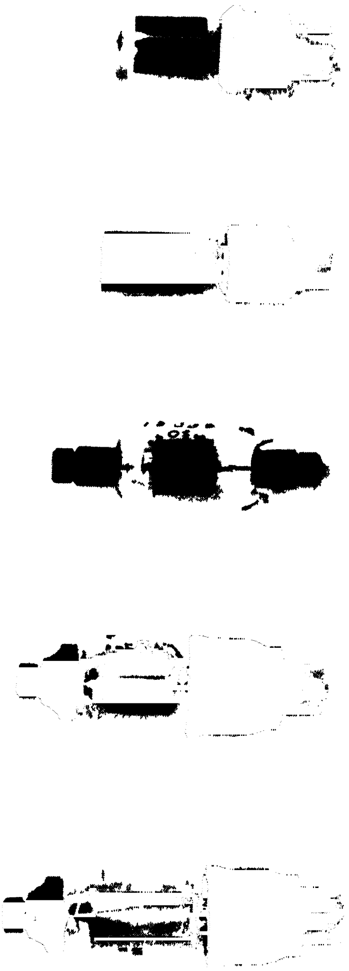


Fig. 9. Improved Types, Caesium-Silver Gas-filled Cells

(*General Electric Co., Ltd*)

It is obvious with such small currents as are obtained from photoelectric cells that high insulation is essential. Frequently both electrodes are brought out to the same end of the bulb (which is the standard American practice) and connected to adjacent pins of an English or American valve base. While this obviously is very convenient, the practice of bringing out the electrodes at opposite ends of the bulb is preferable. The former construction frequently gives rise to an insulation leak between the electrodes during the life of the cell which manifests itself as a falling-off in light sensitivity, actually due to a high resistance path in parallel with the electron path inside the bulb. In Fig. 9 a range of improved types of the caesium-silver oxide cells is shown, in which the construction has been designed in three cases to eliminate insulation troubles and prolong the useful life of the cell. The electrodes being brought out at opposite ends in most types ensures that the insulation resistance path between them, which in that case is the whole interior length of the bulb, is a maximum. Other forms of assembly and mounting are shown in which the same cathode and gas-filling are used, the variations being made to suit different practical requirements.

Dark Current.

In every photocell a small current passes when the cell is not illuminated. This in general consists of two parts—

(*a*) Current due to insulation leakage between the electrodes.

(*b*) An electron emission from the cathode similar to that produced by a small illumination. This is usually termed "dark current."

The latter is always small and generally can be ignored in commercial applications. In scientific investigations the guard ring fitted to all vacuum cells is used to shunt the leakage current from the measuring instrument. Source (*b*) can frequently be considerably reduced by electrode construction. It is obvious that if the illumination under consideration is very small, say, of the order of 10^{-6} lumen, the photoelectric current so produced will also be very small and may be comparable to the dark current.

Hence the necessity for reducing the dark current to a minimum.

The cell construction most suitable to reduce the dark current to a minimum, is that in which the electrodes consist of a centrally placed anode of very small dimensions in the centre of a spherical surface, the whole of which forms the cathode.

Unfortunately, the forms of thin film cathodes which are most efficient for general purposes, have an abnormally large dark current which is in the nature of a thermionic emission, appreciable even at atmospheric temperatures. The presence of this large dark current prevents advantage being taken of the very much greater sensitivity in emission for the measurement of faint illuminations, and their utility for scientific investigations is not as great as might at first appear, but as mentioned above, in most commercial applications where bright lights are used, this dark current is negligible compared with the photoelectric current.

Time Lag.

A great many applications of photocells involve conditions under which the cell is illuminated by light which changes rapidly in intensity, and the photoelectric current is required to follow the changes and maintain a linear relationship with the light even when the fluctuations are rapid.

As will be explained later, to maintain this relationship is the principal difficulty in television and, to a lesser extent, in talking films and picture telegraphy.

Any appreciable time lag in the cell immediately causes distortion in the reproduction.

As far as is known, the emission of electrons from the cathode takes place instantaneously. No one has been able to measure the time interval between the incidence of light on the cathode and the emission of electrons, and as in a vacuum cell this is the only effect taking place, the current will vary proportionately with the fluctuating light. This has been checked by sinusoidal light changes up to supersonic frequencies, and it is certain from various experiments, that any time lag which exists is less than 10^{-8} seconds.

With gas-filled cells used at high magnification there is a slight interval between the incidence of the light and the full cathode emission, due to the fact that the process of ionization does not instantly assume its full value. This time interval cannot be calculated with any certainty because it varies with the shape of the cell and electrodes, on which depend the accumulation of static charges on the bulb, and on a full knowledge of the state of the gas in the cell, which are factors difficult to determine.

As magnification due to gas-filling is reduced by decreasing the applied voltage, the time lag becomes less until with low voltages where there is no ionization, the gas-filled cell becomes practically a vacuum cell in performance and the time interval becomes negligible. This point is dealt with more fully in the chapter on talking films.

In practical applications involving the operation of a relay, any lag in response must be looked for outside the cell, as the time constant of the external circuit is invariably the factor which limits the speed of working.

CHAPTER II

CIRCUIT DIAGRAMS

METHODS of using photoelectric cells depend entirely on the object in view, and the magnitude of the illumination available. Briefly they may be classified into two distinct groups. Firstly, those in which it is desired to obtain some numerical relation between the incident light and the indication on a measuring instrument, by means of which some other quantity under consideration, such as, for instance, the transparency of a liquid, can be determined; and, secondly, those in which it is required to work some alarm, or other mechanism when a comparatively large change in illumination takes place. It will have been understood, from the previous chapter, that vacuum cells are always preferable for the first type of problem owing to their greater stability, while the greater sensitivity of the gas-filled type is an advantage in problems of the second class.

Direct Measurement.

Direct measurement of photoelectric currents may be made by one of the following methods—

(1) By the indication of an electrometer or electroscope connected to the plates of a condenser which is charged by the photoelectric current either for a definite time or to a definite potential (cf. p. 160). An electrometer of the Compton or Lindemann type, in which the instrument itself may provide the necessary capacity, can be used in applying this method, which is, of course, very convenient.

(2) By similarly charging a condenser and neutralizing the charge with the current from another photocell, or from a potentiometer.

(3) By charging a condenser in the same way and discharging it through a ballistic galvanometer.

(4) Direct reading with the photocell in series with a battery and reflecting galvanometer.

The relative sensitivity, accuracy, and advantages of these methods are fully discussed in *Photoelectric Cells*, by Campbell & Ritchie, pp. 107-130 (Pitman), to which the reader should refer for further information. They are capable of dealing with currents of the order of 10^{-15} amp. in the case of method (1) to currents of not less than 10^{-8} amp., which is about the limit for a good reflecting galvanometer, in the case of method (4). They permit of numerous modifications, and for the most part can only be used by skilled observers under laboratory conditions. Method (4) is too obvious to need explanation, and providing sufficient light is available is the simplest and most accurate method of using a cell quantitatively. It is useful, for instance, in measuring the absorption of glass or translucent material. In the case of very minute currents in precision work, many factors make it undesirable to attempt to amplify the current before measurement. Valve amplification, which is so useful in the case of detection, will, unless elaborate precautions are taken, introduce serious errors due to parasitics and lack of constancy caused by small changes in valve characteristics.

Detection.

By far the greater number of problems in industry involve detection of light changes, and here the thermionic valve, the grid glow tube, and the gas-filled relay are of extreme value. For this reason, considerable space is devoted to an elaboration of simple valve relay circuits. It is advantageous wherever possible to convert a problem involving the measurement of light, which seems to lie in the first group of methods, into an arrangement in which some other factor is measured and where the photocell is only required to detect the change in light at predetermined limiting values. Simple valve relay circuits may then be used without introducing difficulties met when attempting to measure small currents with precision.

Principles of Valve Amplification.

Before attempting to describe in detail some typical industrial applications of photocells, each of which generally involves a modification of one of several valve circuits, it is proposed to offer a brief description of these circuits. In practice, the photoelectric cell always acts as a part of a mechanism which performs some function through the agency of the change or the incidence of some form of illumination. It may be that this mechanism is engaged on a simple operation where its duty is only to switch on a lamp when the sun sets, or to record the number of persons entering a building, but whatever it has to do, in every case some change in the light illuminating the cell is made to control an external device, which is usually an electrical circuit. Unfortunately, as we have shown, the photoelectric currents passing in the cell even with the brightest illuminations are too small to operate robust relays or switches directly without amplification, and especially is this difficulty felt in industrial applications where vibration, unskilled operators, and other adverse conditions mitigate against the use of delicate instruments, such as galvanometers and electrometers capable of indicating the small currents. We have, therefore, been forced to develop and use amplifying circuits to enable relays and power contactors to be controlled by the minute current changes in the photoelectric cell. The ordinary thermionic valve, the grid glow tube, and the gas-filled relay have been found to be eminently suitable. To be efficient, reliable, and not prohibitive in initial cost and running expenses, these circuits must be very simple, incorporating standard components, and if at all possible, employing not more than one valve, since the definite working life of the filaments of the valves imposes a replacement limit to the operation of the complete unit.

The Single Valve Relay.

The obvious method of using a photocell to control a relay through the agency of a thermionic valve is to arrange that the cell controls the grid potential of the valve, and then to include the relay in the anode circuit. Two straightforward ways of doing this are shown in Figs. 10 and 11. Attention is called to the fact that these remarks only apply to applications where the changes of light are intermittent and where time lags in the operation of the relay of the order of $\frac{1}{25}$ of a second do not matter. It must also be remembered that the light changes may follow each other after intervals varying from a fraction of a second to several hours, or even days.

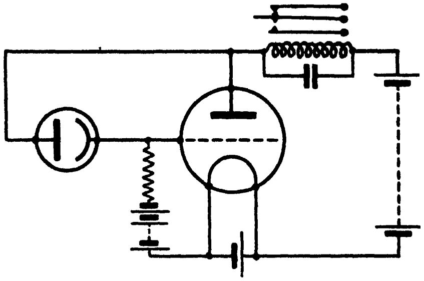


FIG. 10. AMERICAN ARRANGEMENT OF PHOTOCELL AMPLIFIER CIRCUIT

Before discussing in detail the functioning of such arrangements it is necessary to trace out the currents and potentials involved in different parts of the grid circuit, as these factors decide whether the photocell can control the anode current or not. It should be noticed that in the circuits of Figs. 10 and 11, and in any of the modifications mentioned in this chapter, the valve, following its static characteristics, itself acts as a simple relay, the anode current being controlled so as to be above or below the critical value at which the mechanical relay opens or closes. As is well known, the anode current is a function of the grid potential, and in these circuits this is influenced by currents from four sources—

(*a*) The normal grid current of the valve due chiefly to electrons from the filament reaching the grid. Sometimes this current is reversed owing to the bombarding electrons liberating electrons from the grid as a secondary emission.

(*b*) The dark current of the photocell. As explained previously, this is due to a small cathode emission. Usually it is too small to influence the circuit but is occasionally sufficient to give trouble.

(*c*) Insulation leakage current. This is due to bad insulation of the components of the circuit and leakage over the surface of the photocell. This current can be a very serious factor affecting the operation of the circuit.

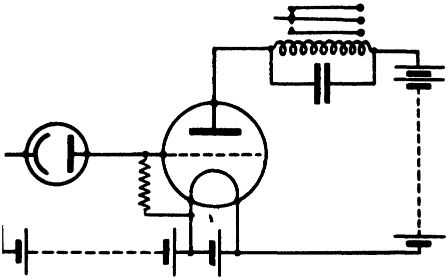


FIG. 11. THE PHOTOCELL AMPLIFIER CIRCUIT FOR BATTERY OPERATION

(*d*) The photoelectric current or true cathode emission due to the incidence of light on the photocell. In darkness this is zero.

American Circuit.

Examining Fig. 10, which will be referred to hereafter as the American circuit, as it is the arrangement most generally used by the manufacturers of that Continent, it will be seen that the connections supply the valve anode and photocell currents from a common high-tension battery through the energizing coils of the relay. The photoelectric current (*d*) due to light on the cathode in this case tends to maintain the grid of the valve at a slightly positive potential. It is, therefore, necessary to apply negative grid bias to counteract this positive potential when the photocell is in the dark (i.e. when current (*d*) is zero but (*b*) and (*c*) may be tending to keep the grid positive), or when the illumination is less than the value at which the relay is required to operate. This negative grid bias will keep the anode current below the critical value for the relay, and hence, an increase of light on the photocell will change the grid potential from slightly negative to positive, increasing the anode current, thus energizing the relay, and closing its contacts. The minimum light required to operate the relay can be controlled by the grid bias potential, and it is sometimes convenient to have a variable high-resistence potentiometer so that the requisite value of potential can be easily found by experiment. The existence of new types of four electrode valves enable the circuit to be operated with the same efficiency but with very low potentials, as the modification in Fig. 13 shows clearly.

Whereas in the American circuit the anode potential is usually about 100 volts, with four-electrode valves only 20 volts are required, a valuable consideration when these circuits are installed away from electricity supplies and have to run for long periods on dry batteries.

It is noteworthy that the condition of darkness on the photocell corresponds to the condition which obtains when the valve filament circuit is opened or the anode potential reduced, and so if the circuit is to be used on the automatic control of illumination by daylight, any failure of the valve or deterioration of the batteries automatically switches on the lights and announces the defect. An important point to guard against (mentioned in the previous chapter), is that the glow discharge will pass in the photocell at a voltage determined by the greatest amount of light on the cathode, and so if the cell is to be subjected to large light changes it may be necessary to use a separate and lower potential tapping for the cell. For this reason this circuit is not particularly adaptable to mains operation.

Standard G.E.C. Circuit.

Figure 11 shows a single valve circuit in which the photocell is connected with its electrodes in the reverse direction to that of the American practice, the arrangement shown in the diagram being that required for battery operation. Although the additional battery required to supply the cell potential may seem an extra complication, the circuit has the merit in that it is readily adaptable for operation directly from the electricity supply mains. It is therefore the one which will be particularly described and illustrated in this chapter. Normally with the cell dark, the grid is at zero potential and a current flows in the anode circuit energizing the relay. With light incident on the cell the photoelectric current (*d*) will flow, representing the passage of electrons to the grid of the valve. As soon as this current is great enough to neutralize the grid current (*a*) of the valve, the grid takes up a negative potential and the anode current is reduced. When the light is cut off, the grid leak resistance allows the original negative charge to escape and restores the grid to its condition of zero potential relative to the filament. It should be clear then, that with the use of old potassium cells having low sensitivities, the photoelectric emission was occasionally too small to neutralize the grid current of the valve, and in consequence the circuit functioned badly unless the valves were selected to secure very low grid currents and very bright light sources were used. The sensitivity could be improved by increasing the value of the grid leak resistance but this led to further difficulties.

Owing to the shape of the grid current characteristic of a valve, the amount of light required to reduce the grid current to zero is greater than that required to maintain it at zero, so the arrangement became very sensitive to light incident on the photocell, and once having detected light, would depend on the insulation leakage current (*c*) to restore the grid circuit to its original state, which occasionally took several seconds. It is possible to make grid leaks of the order of 300 megohms specially for this purpose to secure quick resetting after the detection of light, and valves of the type best suited to this circuit from other points of view were specially selected for low grid current and given an "ageing" treatment before passing into stock for use with these photocell circuits. With these precautions the operation was then satisfactory.

In the new caesium-on-silver cells with certain forms of electrode construction the current (*c*) in the cell, due chiefly to internal leakage, is sometimes sufficient to keep the grid permanently negative when the cell is in the dark, even without a grid leak, with the result that the circuit becomes insensitive to light changes and refuses to operate, hence the necessity of grid leak resistances of much lower values—10-20 megohms being suitable to keep the grid at zero potential in darkness. At the same time these lower values of resistance allow the high standard of insulation previously required between the grid and filament of the valve to be lowered to reasonable values, and they are also sufficient to make the circuit very quick in operation, so that the speed of response is now only limited by the inertia of the mechanical relay and not by the time constant of the grid circuit. Decreasing still further the value of the grid leak resistance reduces the sensitivity of the circuit to light, and this can be used as an alternative to an adjustable diaphragm used originally as a sensitivity control.

Mains Operation.

When the location of the photocell mechanism is near electricity supply mains it is, of course, a great advantage to be able to dispense with batteries and run the complete circuit from the mains. Only in a very few applications have battery operated circuits been installed near supply mains, and then these have only been used because abnormal variations in mains voltage upset the performance of the installation. Even then it has been found possible in some cases to replace the battery installations with all-mains sets under barretter control. The simplicity of the circuit when adapted for mains operation is shown in Fig. 12. The valve (an Osram P410 is a specially suitable type) has its filament connected in series with two resistances across the supply mains, the sum of these two resistances being that required to pass the correct filament current. The anode of the valve is connected through the coils of the relay to one of these resistances so that the voltage drop therein constitutes the anode voltage of the valve. Similarly the voltage drop in the other resistance gives the potential for the photocell.

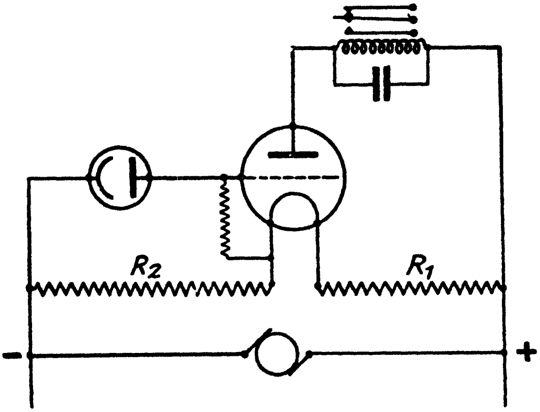


Fig. 12. The Photocell Amplifier Circuit for "All Mains" Operation

When there is no light on the cell, it passes no current, and, hence, the grid of the valve is free, so that a certain anode current passes through the relay coils holding the relay in the ON position. When the cell is illuminated it passes a current which opposes the grid current of the valve, and as the light increases a condition is reached when the photoelectric current exceeds the grid current, the grid becomes negatively biased, and the anode current is reduced to zero. The relay contacts then move to the OFF position.

The same circuit may be used on alternating current electricity supplies. When the direction of supply voltage is in the reverse direction to that indicated in Fig. 12 (i.e. during the negative half-cycle), the valve will pass no current since the anode is negative relative to the filament.

The set thus works only on the positive half-cycles, and the current through the relay coils is unidirectional at a frequency equal to that of the supply. The valve and photocell in fact act as their own rectifiers, and no smoothing arrangements are necessary. As the R.M.S. value of the anode current will, in this case, be roughly 70 per cent of that with a direct current the relay supply has to be fairly sensitive. A further section of this chapter is devoted to a description of suitable relays developed for this application.

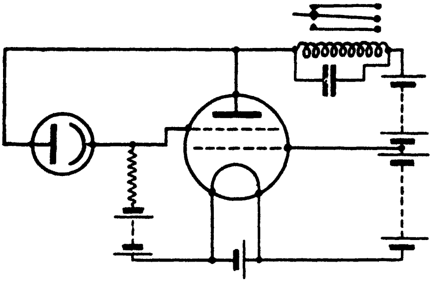


FIG. 13. PHOTOCELL AMPLIFIER CIRCUIT FOR FOUR ELECTRODE VALVES

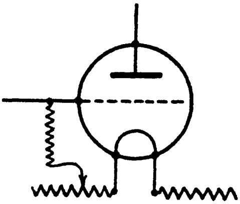


FIG. 14. NEGATIVE GRID BIAS FOR D.C. OPERATION

When operating on A.C. the photocell may, however, pass a small positive charge to the grid of the valve owing to the fact that its anode will always be slightly photoelectric, but the effects of this can be neutralized if a small condenser is connected between grid and filament of the valve. This, however, is not used in the latest pattern of unit.

In some cases it may be necessary to have tapping points on the mains resistances to reduce the cell voltage and to provide negative grid bias for the valve, as shown in Fig. 14. This latter precaution is only necessary if the anode voltage (which is mains voltage less cell voltage) is so high that the emission from the filament may seriously reduce the life of the valve. In the standard unit this is not considered a necessary refinement, as it has been arranged that the valve filaments are considerably under-run, thus reducing the emission without impairing the efficiency of operation of the relay. Tappings are provided, however, on one of the resistances to allow for differences in mains voltages, in steps suitable for 200, 220, and 240 volts.

Occasionally it is required to separate the photocell from the rest of the equipment where space does not permit the whole circuit to be located in one position, and it is then preferable to keep the valve and cell together, otherwise on alternating current systems some difficulty may be experienced, as stray capacities, and lower insulation resistance, will allow potential changes to be communicated to the grid and upset the operation of the circuit.

Owing to the fact that the filament is not at earth potential, small capacities between the grid and other parts of the circuit and earth connections will reduce the sensitivity and in some cases prevent the circuit operating. For this reason a small insulated metal screen is placed between the metal box containing the resistances, connections, etc., and the photocell and valve, and if extension leads are necessary they should be short and screened, and well separated from each other.

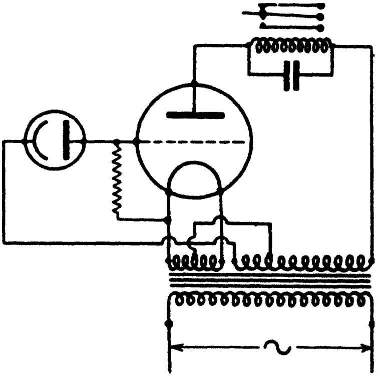


FIG. 15. PHOTOCELL AMPLIFIER CIRCUIT FOR A C. MAINS OPERATION

An alternative circuit for alternating current operation is given in Fig. 15, which has the merit of low-power consumption. The previous circuit consumes 20 watts continuously from the mains while this alternative requires less than 2 watts. The chief drawback is the expensive mains transformer which more than doubles the manufacturing cost of the equipment, and the more complicated connections. There is nothing to choose between this and the standard circuit as far as performance is concerned.

Amplifier Unit.

Fig. 16 shows an illustration of a typical unit incorporating the circuit of Fig. 12. The components are mounted on an aluminium base plate secured to the bottom of the case by three studs, so that the assembly is easily and quickly withdrawn for inspection. The outer case is of cast iron and weatherproof. The glass aperture can be removed if desired and replaced by an adjustable iris diaphragm, so that close control can be made on the amount of light reaching the cell.

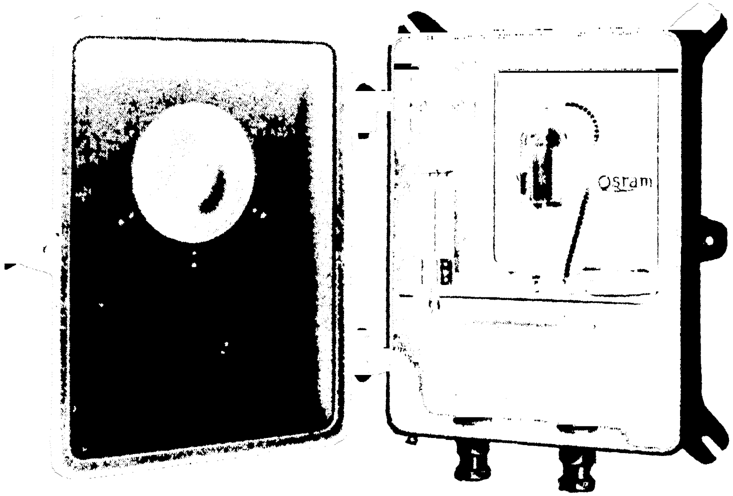


FIG. 16. PHOTOCELL AMPLIFIER
(General Electric Co., Ltd.)

Quantitative Measurements.

Quantitative measurements of fair accuracy can be made by means of a slight modification of the circuit shown in Fig. 10. It is necessary to use a vacuum cell for constancy, with a separate voltage tapping of about 20. The grid bias of the valve, which may be of the L.P.2 type, should be adjusted so that during the change of anode current, the operating point of the valve does not move off the straight portion of its characteristic, otherwise the relation between incident light and anode current cannot be linear. The value of the grid leak is determined by the range of illumination through which measurements are to be made, and must be fixed in any case by preliminary experiment. Some current will flow in the anode circuit when the photocell is dark, and zero adjustment of this current must be made, not by increasing the grid bias, but by an auxiliary battery across the anode meter with a suitable resistance to give fine adjustment. A shunted milliammeter (0-1 ma) is suitable for this purpose. An accuracy of about 5 per cent is possible with this arrangement. No attempt should, of course, be made to operate the circuit from supply mains.

The Phototube.

Several investigators have devoted attention to the development of a combined photocell and thermionic valve, the electrode assembly of both units being housed in the same bulb. Such combinations are quite practicable, and in some cases have been used successfully. The resulting product is, however, less efficient than the combination of separate units.

The Grid Glow Tube.

Circuits employing the ordinary thermionic valve which have been described, provide the necessary amplification in order that small commercial relays capable of dealing, without extra contactor gear, with currents of about 0·5 amperes, can be controlled by photocells.

There are, however, among the ever-increasing commercial uses of light sensitive devices, cases where a moderate current relay of this type is entirely inadequate, and where larger contactors, or circuit breakers, are necessary. These may, of course, be operated by having several successive relays and contactors, but with the recent development of the grid glow tube, and the gas-filled relay, large currents can be controlled directly from the photoelectric current.

The ordinary "beehive" neon lamp is familiar to everyone on account of its characteristic red glow and low current consumption, while larger types working on the same principle are to be seen as advertisement signs and indicators. Unlike the ordinary incandescent filament lamp, no current passes in a discharge tube of this kind until the applied voltage is raised above a certain value known as the striking voltage. Once this discharge has started, however, the voltage can be decreased much below the striking voltage before extinction of the discharge takes place. A protective resistance in series is essential when using a glow tube for the same reason that a gas-filled photocell requires protection, otherwise a heavy current may pass when the discharge starts and shatter the tube. This critical starting voltage enables a modification of the ordinary neon discharge tube to be used as a relay for photoelectric cells in the following manner—

Near the anode of the tube is placed a third electrode, thus forming a triode consisting of cathode, anode, and control grid, the last being highly insulated from the other two. If a suitable voltage is now applied across the tube, leaving the grid entirely disconnected from the circuit, the high velocity electrons, which would normally cause ionization, impinge upon the grid, which thus assumes a negative potential, and the discharge will not start. By conducting the charge away from the grid by an illuminated photocell or other means, the discharge will pass and a current will flow which can be used to energize a relay. Once started, however, this discharge cannot be stopped without breaking the circuit or reducing the potential applied to the electrodes, because ionization produces a coating of positive ions round the grid, and this causes the grid control to be no longer effective. The principle of operation should be clearly understood, as it plays a great part in the design of circuits described in this section. Here then, is a true trigger circuit in which the current can be started but not stopped by the photocell, and the circuit must be broken independently in order to repeat the process of detection. The advantage of the glow tube is that in its quiescent state, it passes no current, there is freedom from inertia and moving parts, and consequently no trouble from vibration. It is usual to employ vacuum cells with these tubes, as the adjustment is frequently critical and may become unstable with a gas-filled cell. An impulse current of the order of 10^{-10} amperes is all that is required to operate the glow tube, which then passes a secondary current of anything between 10 and 100 milliamperes according to the size of tube. It is, therefore, very useful for detecting feeble illuminations. An extra pair of contacts, which are in series with the discharge path, can be fitted to the relay, so that it will give one impulse with the incidence of light and reset itself for the next detection. If light is continuously on the cell, the relay will repeatedly open and close, giving a series of signals to the external circuit.

The Thyratron or Gas-filled Relay.

The thyratron, or gas-filled relay as generally understood, is an improvement of the grid glow tube. It is, in reality, a hot cathode mercury vapour rectifier with an extra control electrode. Whereas the cold cathode tubes can handle currents of the order of 100 milliamperes, the gas-filled relay can be designed to control up to twenty kilowatts with an expenditure of only one microwatt of energy in the control circuit.

At low anode voltage the gas-filled relay passes a current similar to that in an ordinary hard valve, but saturation takes place at 15–20 volts. If this voltage is exceeded, a heavy current will pass and the tube will be destroyed unless a limiting resistance is included in the anode circuit. In a similar manner to the glow tube, the gas-filled relay may be controlled by a photocell. Negative bias applied to the control grid prevents the anode discharge from passing, and the photocell can be arranged so that light incident upon it will reduce this negative bias below the critical voltage which is the potential difference between grid and cathode, and which just allows the discharge to start. However, in common with the glow tube, once the discharge has started in the tube, the grid exercises no further control until the anode circuit has been broken or its polarity reversed. Thus on D.C. circuits, a means of breaking the anode circuit to reset the apparatus is required in the same way as with the glow tube. The method described of using a special anode relay could be employed, or even some form of motor-driven rotary switch, but as far as the photocell is concerned, these methods are of little or no improvement on the thermionic valve with a train of relays, as they introduce added complications. As the time interval between the instant when the grid potential is reduced below its critical value and the passage of the discharge is very small—it may be as low as $\frac{1}{1000}$ sec.—the use of the gas-filled relay with D.C. on the anode is convenient for detecting a flash of light of short duration where a relay with a movable armature would not have sufficient time to operate.

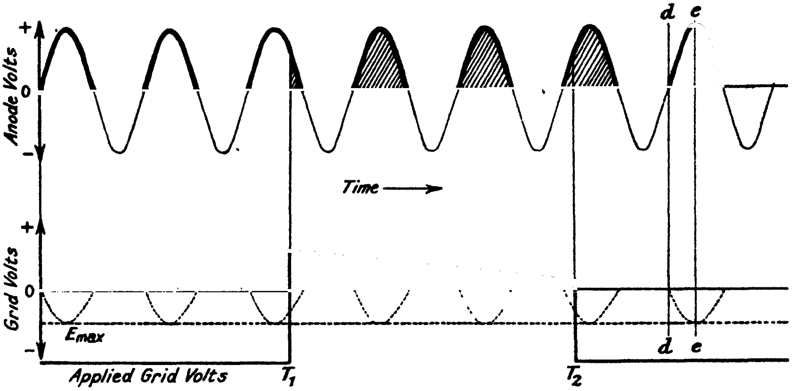


FIG. 17A. CHARACTERISTICS OF GAS-FILLED RELAYS

On A.C. circuits, however, the gas-filled relay has multifarious possibilities, for now the anode current ceases and the tube resets itself automatically when each half-cycle of the alternating e.m.f. causes the anode to become negative with respect to the cathode. If then the critical grid voltage of the tube is E, when we apply alternating anode voltage, anode current will flow during every positive half-cycle as long as the grid is at a more positive potential than E, but will not flow if it is more negative than E.

It is desirable at this point to refer to Fig. 17A, where the last paragraph is explained diagrammatically. The alternating anode voltage is here indicated as a sine wave, and the shaded area represents the time during which anode current flows. A steady potential is applied to the grid, say, from a battery. Let us assume that the grid starts by being at a potential more negative than the critical voltage which is represented by the dotted sine curve of opposite phase to the anode volts. In this state, no anode current flows, but if at time T_1 the grid is made to assume a potential more positive than the critical voltage during a positive half-cycle of anode volts, anode current immediately flows and continues to do so as long as the grid is more positive than E. Naturally, no current flows while the anode potential is reversed. It will be seen that at T_2, where the grid volts have been changed to become more negative than E, during a positive half-cycle, the grid cannot resume control, as the tube is passing current, until the next cycle, that is, until the circuit has been reset during the following negative half-cycle. It will also be seen that between $E_{max.}$ and zero, there is a critical grid voltage for every value of anode voltage over the quarter-cycle *de*. Thus grid voltages, slowly varying between $E_{max.}$ and zero, will cause a progressive control of the average anode current such as could be measured with a moving-coil meter. Fig. 17B shows this, the ordinates being the same as those in Fig. 17A.

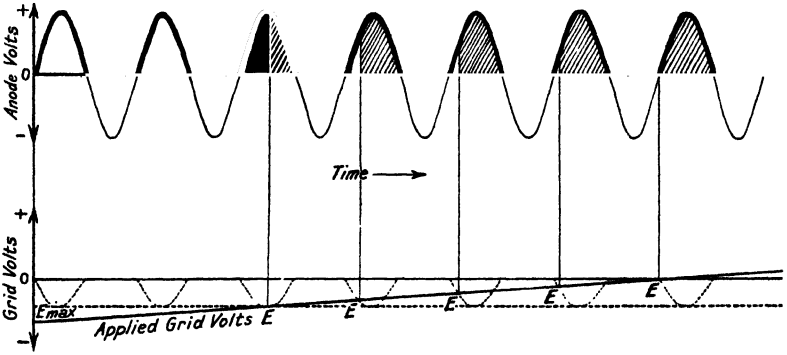


FIG. 17B. CHARACTERISTICS OF GAS-FILLED RELAYS

Grid control of this nature may be obtained photoelectrically in circuits similar in character to those of Fig. 18A, but they are little used because a battery is required for the photocell, and progressive anode control is only obtained over the range half to full anode current.

By far the most interesting and useful gas-filled relay and photocell combination is that using a phase change method of progressive control.

If it is remembered that the phase change method controls the mean anode current in precisely the same manner as the method just described, i.e. by "triggering off" the discharge at different points of the positive half-cycle, the principle of operation will be easily understood.

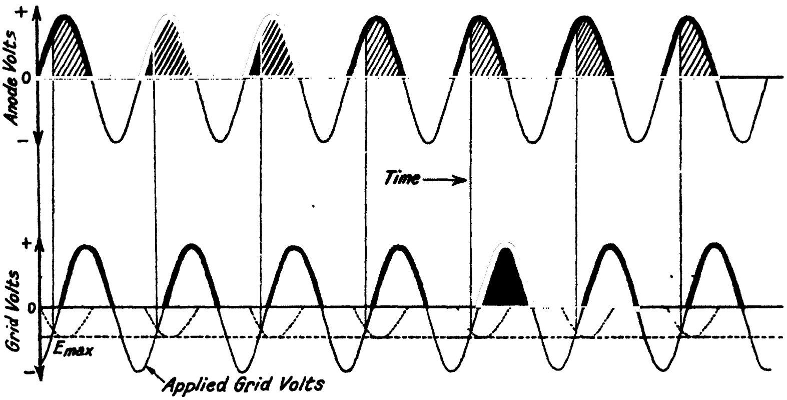


FIG. 17C. CHARACTERISTICS OF GAS-FILLED RELAYS

Let us again assume that the critical grid voltage of the tube is E, and the applied grid volts in phase opposition to the anode volts with an amplitude greater than E. Current will not flow in the anode circuit, because at every point during the positive half-cycle, when the tube might be operating, the grid potential is more negative than E. If, however, the grid volts, still of the same amplitude, are caused to lag behind the anode volts by a small phase angle, at one part of the positive half-cycle the grid will be more negative than E, and at the other will be more positive, Fig. 17C. Thus we obtain anode current during part of the positive half-cycle, the magnitude of which is dependent on the phase angle between the anode voltage and the grid voltage.

This phase change between the applied grid potential and the critical grid potential can be obtained by a simple bridge connection of a capacity and high resistance, as shown in Fig. 18C. Naturally, the high resistance may be replaced by a photocell, so that changes in illumination on the cell will vary its impedance and, hence, the

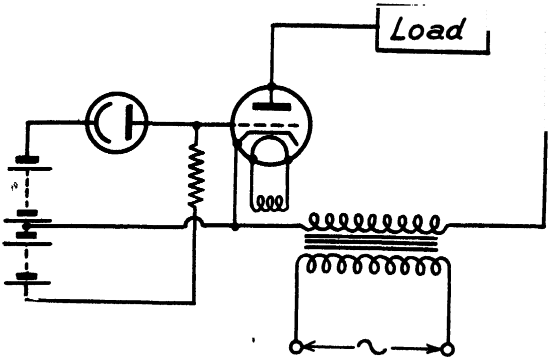


Fig. 18a. D.C. on Grid

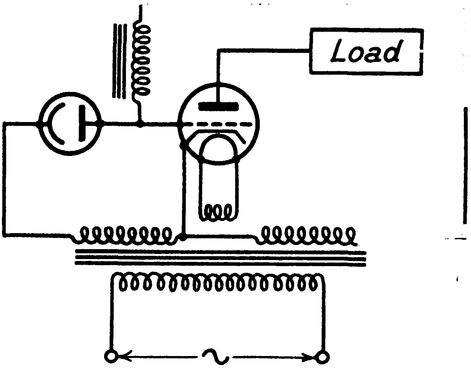


Fig. 18b. Phase Change, Inductive Method

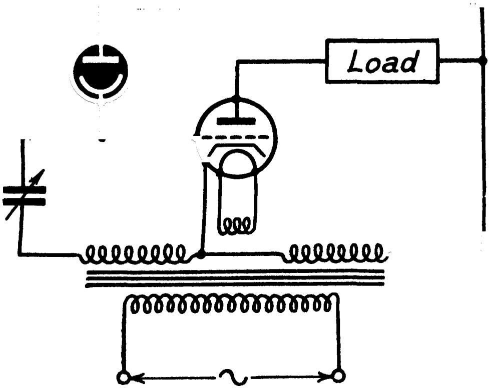


Fig. 18c. Phase Change, Capacity Method

phase angle of the applied grid potential. Thus the mean anode current of the tube becomes proportional to the illumination over a certain range.

This briefly is the theory of operation of the gas-filled relay. The whole subject opens out such vast possibilities that one hesitates to predict the developments of the near future. We have indicated here the elementary theory of these new electronic devices, and outlined their circuits with the knowledge that they may eventually replace the thermionic valve when they are perfected.

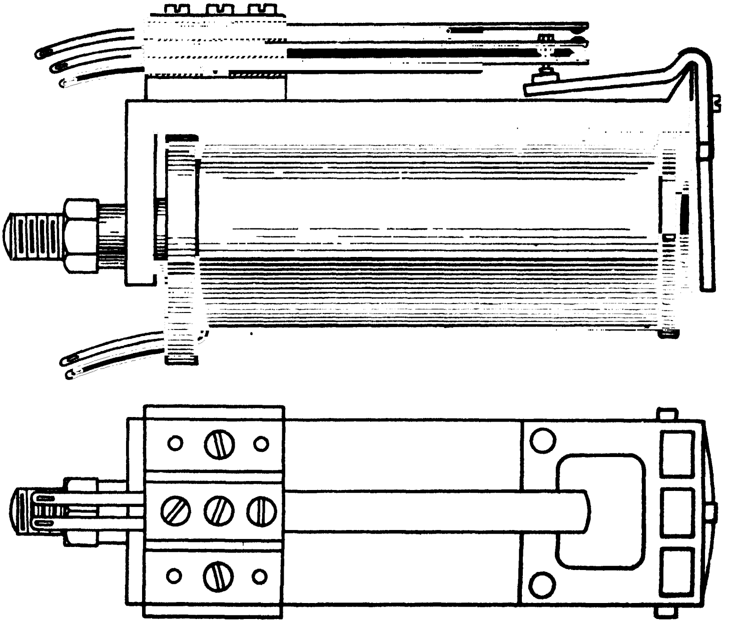


FIG. 19. TELEPHONE TYPE RELAY
(*General Electric Co., Ltd.*)

Relays.

As previously explained, the standard photocell unit contains a small relay which closes its contacts when current of more than 2 milliamperes passes through its energizing coil. This relay has phosphor-bronze contacts with tungsten points, which will break 0·25 amperes on a non-inductive circuit without burning or pitting. Usually, only three contacts are used to give a single-pole change over, but provision is made on the relay to accommodate extra sets of contacts if the particular application requires this elaboration. For example, it may be necessary to arrange for the relay to lock itself in magnetically after it has closed, and thus keep the alarm circuit in operation until released by an independent switch, which will reset the apparatus. Also it may be necessary to control two or three separate circuits by the movement of the one relay. Fig. 19 shows a side-view and plan of such a relay. It will be noted that here there is only one set of contacts, but that provision is made for two extra sets, one on either side of the one shown. A mercury switch can be fitted to this relay instead of these spring contacts, so that currents of greater magnitude can be controlled. Mercury switches are, however, affected by vibration, and in addition the movement of the armature is usually rather small, so that their use is limited.

FIG 20 SMALL POWER CONTACTOR

For controlling larger currents, a power contactor must follow the small relay, so that the latter only carries the current needed to energize the operating coil. Fig. 20 shows a small contactor for dealing with currents up to twenty amperes. As the operating coil of such switchgear is highly inductive, a resistance should be connected across its terminals to absorb the induced voltage when the circuit is broken, otherwise the tungsten contacts of the relay may be burnt by the arc produced. A neon lamp can also be used for this purpose.

Many elaborate relay circuits and combinations have been devised to suit individual requirements of different cases. Some of these are referred to in the following pages, but many are too specialized to be of any interest to the general reader, and will, therefore, not be dealt with.

Light Sources.

When installing a photocell amplifier, the question of deciding on a suitable source of illumination naturally arises. Most optical projectors in common use are unsuitable for photoelectric apparatus, as they are generally designed to throw a comparatively wide beam of light from a high wattage lamp. Since any light which falls outside the window of the photocell unit is wasted, as it does not reach the cathode of the cell, it is desirable to have a beam which is roughly two or three inches in diameter at the window. The ideal arrangement consists of a parallel beam of this diameter, for then no adjustment is required for focusing, and the amount of light reaching the amplifier is practically constant for any reasonable distance.

Most commercial projectors obtain this result by introducing a diaphragm without any change in the optical system. This, of course, merely cuts off most of the light and is optically very inefficient. Except in special cases, commercial projectors designed for other work are not recommended since ample illumination can be obtained from low wattage lamps of the automobile type.

Theoretically, a point source of illumination with a parabolic mirror is the ideal arrangement, but it is impossible to obtain a point source with metal filament lamps, and, in addition, good parabolic mirrors are expensive. For maximum illumination it is better to use a double convex lens and form an image of the filament of the lamp, say, a twelve volt thirty-six watt automobile lamp on the cathode of the cell. If the set is to be used at more than one fixed distance from the light source, an approximately parallel beam will be obtained if the lamp is at the focus of the lens. Otherwise a sharp image of the filament may be focused on the window of the amplifier.

The amount of light collected from the lamp by such a lens is obviously less than that collected by a parabolic mirror, but the intensity of the beam at the distant point will be greater, owing to the spread which will occur in the case of the mirror, since the filament is not a point source. The amount of light which the lens will collect from the filament is proportional to the solid angle which the spherical surface subtends at the source of illumination, so that from this consideration the lens should be of large diameter and short focal length. The size of the image of the filament formed is, however, almost inversely proportional to the focal length of the lens, so that some compromise is essential.

A very convenient light unit is shown in Fig. 21. This is designed

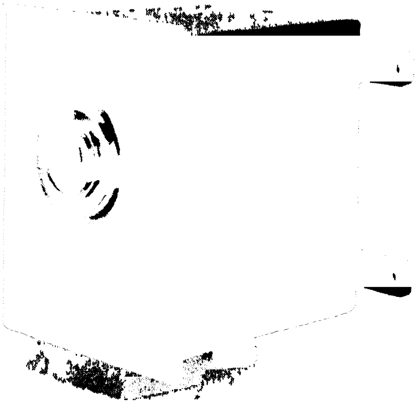


FIG. 21 LIGHT UNIT

to give a constant small spot at all distances up to about fifty feet, and contains a twelve volt thirty-six watt automobile lamp operated through a transformer from A.C. supply mains. This arrangement is efficient; it avoids the use of the projector type lamp with its comparatively short life, and is suitable for use with the amplifier unit previously described up to a distance of about fifty feet. There is no really satisfactory solution to the problem for D.C. supply. The type of lamp described can, of course, be used on an accumulator or from the mains with a series resistance, but the disadvantages are obvious. The only alternative is the high voltage projector lamp.

Invisible Ray Operation.

Sometimes it is required to control the photocell unit by means of infra red rays, so that no visible light is perceptible, and this can be accomplished by introducing a suitable filter, which will absorb the visible radiation in front of the lamp.

The limit of visibility for most individuals is about 7,500 A.U., so that it is necessary to obtain a filter which transmits only radiations of wave-lengths above this point. Thin sheet ebonite may be used for this purpose. It is in general satisfactory, and has the merit of cheapness but, like gelatine filters, is not quite permanent and needs occasional replacement. A specially prepared glass is also made for this purpose, and is claimed to be quite permanent. The transmission curve for a sample of this glass is shown in Fig. 22. As the infra-red radiation forms only a small part of the total radiation of the light source, and as also some absorption of even the infra-red takes place in the filter, the radiation actually reaching the photocell is very much reduced, and a higher wattage lamp will be required to operate the unit over the same distance than if a filter were not used. In many cases it is not essential for the beam to be absolutely invisible. A

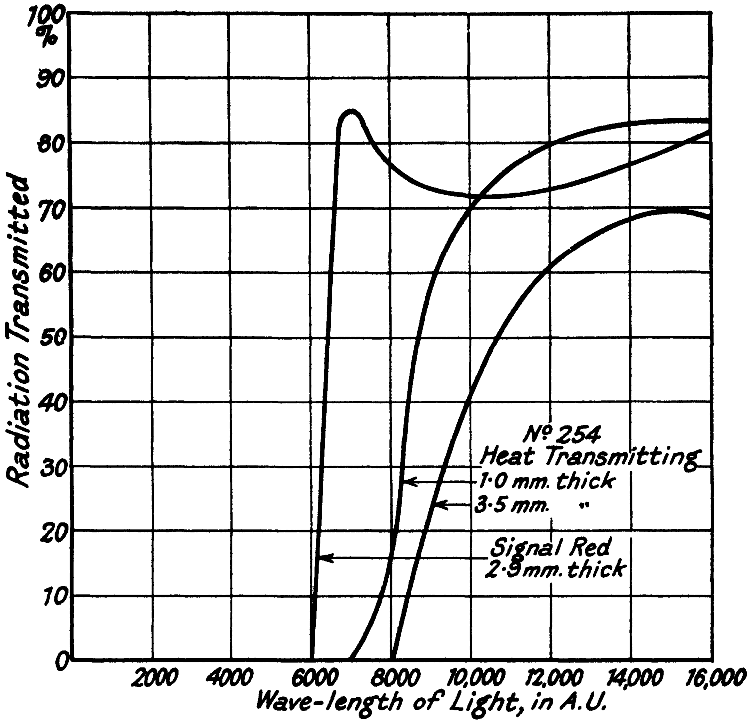


FIG. 22 INFRA-RED TRANSMISSION CURVES OF NO. 254 AND SIGNAL RED GLASSES

single thickness of ·006 in. sheet ebonite makes the transmitted beam a dark red which, when focused, can only be seen by viewing it in the direction of projection, especially if the lamp-house is concealed or built into the surrounding structure, as in the case of burglar alarm installations, so that its presence is not obvious from a cursory inspection. The extent to which the light source is obscured is, therefore, a matter of compromise; for the less visible the controlling beam, the shorter the distance over which the unit will operate satisfactorily.

CHAPTER III

COUNTING AND TIMING GEAR

Simple Applications.

THE circuits described in the previous chapter can be very conveniently modified to actuate counting devices where mechanical or electrical recorders operated by contacts are unsuitable.

For instance, if the articles to be counted are irregular in shape and size, or light in weight, the successful operation of a counter by mechanical contacts may present some difficulty. A mechanical contact in such cases will generally be either too light to secure positive action or too heavy to enable the articles to operate it.

The photoelectric equipment cannot obviously compete in cost with a simple contact system, but it is frequently the only method which can be successfully employed. Fig. 23 is an illustration of the equipment supplied by the General Electric Co. Ltd., and installed at the Manchester Offices of the *Daily Herald*. The adoption of the photoelectric equipment was decided upon by the *Daily Herald* after numerous other methods had proved unsatisfactory for accurately recording the output of the printing presses to the publishing and dispatch room. Copies of newspapers as delivered by the machines are placed in five-quire bundles on moving belts traversing the length of the machine-room. The conveyor belts carry their load at the rate of 120 feet per minute in to the dispatch department.

The photocell circuit used is the one shown in Fig. 12, using the standard OSRAM C.M.G.8 photocell. The relay, operated by the interruption of the beam of light directed on to the photocell, operates a contactor which in turn completes a local circuit including the actual recorders, the latter being of the Veeder Magnetic type. The recorders are installed in the department offices, and are as much as fifty yards away from the machine-room. Bundles of newspapers at certain periods intercept the beam of light fairly rapidly when consecutive ones are deposited on the conveyor in close formation, the shortest interval between the passage of the bundles being about ·05 second. The source of illumination is a six volt lamp operated from A.C. mains through a step-down transformer, and the light from this lamp is directed on to the photocell in a parallel beam by means of a small convex lens. The great advantage of this method of recording is that it allows the overseers to remain in their offices if necessary and yet still be in close touch with the progress of the presses.

Not only is this a highly satisfactory method of counting the actual output of a manufacturing process, but it will conveniently record the extent to which the output schedule is lacking. For instance, generally the manufactured article will, after delivery from a machine,

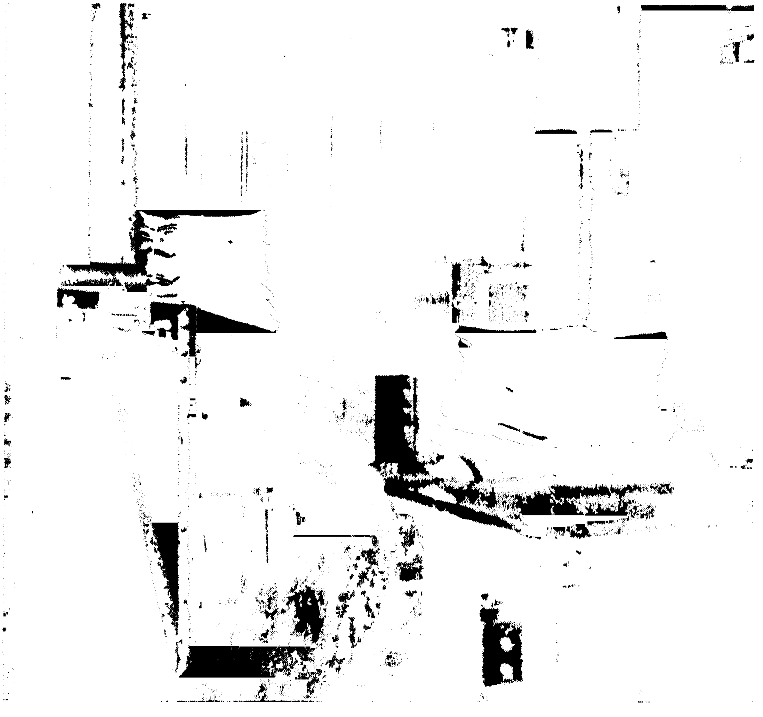


FIG 23. NEWSPAPER COUNTING GEAR

(Daily Herald)

be fed on to a conveyor, the regular output of the machine enabling the conveyor to deliver the articles equally spaced along its length. It may happen, however, that owing to inexperience or inefficiency the operator cannot feed the machine at the proper speed, and there are accordingly a number of misses on the output conveyor. The photocell can then be used to differentiate the "full" and the "empties," and the modification of the standard circuit is shown in Fig. 24. Reference should be made to Fig. 12 for a full description of the operation of the circuit. The switch *A* is closed mechanically by an attachment to the machine which comes into operation when the conveyor pocket is passing underneath the beam of light. At this instant one of two things happens—if the conveyor pocket is empty, the beam of light is not interrupted, contacts *TM* remain closed, and meter *C* records the fact. If the conveyor pocket is full, the beam of light is interrupted, the relay *D* energized, and contacts *ST* close. In this case meter *F* records the event. In this way it is easy to have an additional check on output, not the least advantage being that the equipment operates only when the machine is working and, therefore, obviates the guesswork which occurs in correcting for stoppages of a machine working to a time schedule. The resistance shown across switch *A* is merely to prevent the anode circuit being broken. Its value, say, 500,000 ohms, is too high to prevent *D* operating unless *A* is closed.

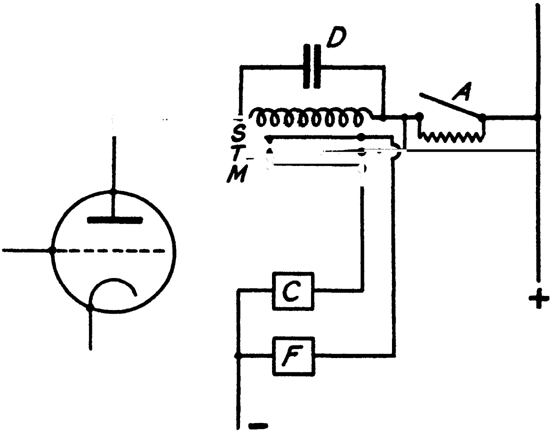


FIG. 24. CIRCUIT FOR SELECTIVE COUNTING

Numerous modifications of this circuit, and the simpler one described in the previous example of newspaper counting, are of course possible. Thus, for example, it is easy to count only those objects whose dimensions exceed specified limits. In fact, not only can they be counted, but they may be selected according to size. If two light beams and photocells are arranged parallel to one another, and the counter connected so that it operates only when both beams are obscured, then if the distance apart of the objects is large enough, only those whose length exceeds this distance will be recorded. Alternatively, instead of a counter, a mechanism may be actuated which will separate the large objects from the small ones.

One-way Recording.

Another interesting and useful counting device is that which records objects passing in one direction only and neglects those moving in the reverse direction. Incidentally, this arrangement is useful for many other purposes than counting. The equipment consists of two photocells placed at a distance so that the shadow cast by the object is wide enough to cover them both at once. In their valve circuits are two interconnected relays *L* and *M* (Fig. 25), the contacts of *L* being normally closed, and those of *M* normally open, i.e. in the state when the relay is not energized.

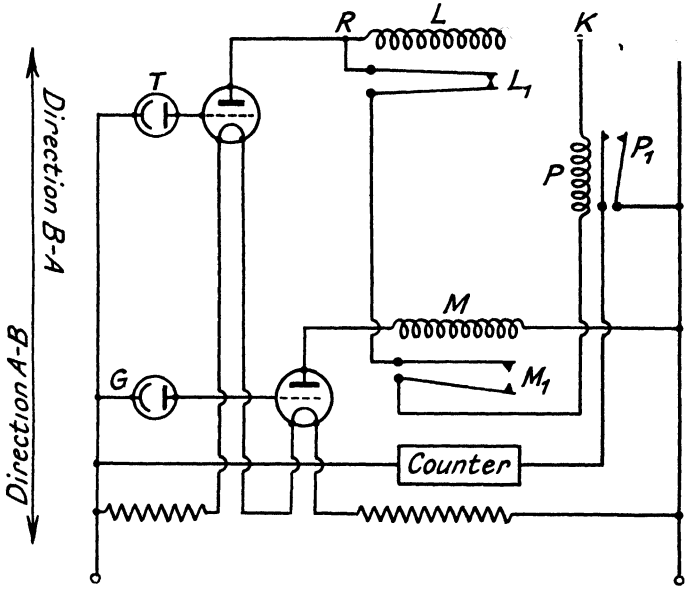


Fig. 25. "One-way" Counting

When current passes through either of these coils, the contacts move from the normal to the opposite position, that is, from closed to open, and *vice versa*. The coils *L* and *M* are of high resistance compared with the coil *P*, or have resistances in series with them to secure this condition. *L* and *M* are control relays, determining by their sequence of operation whether the relay *P* which actuates the counter, is brought into action or not. The line *AB* indicates the passage of the interrupting shadow. The photocells connected to the grid circuit of the respective valves are referred to by the letters *G* and *T*.

It can be shown that if the object passes in the direction *AB* it will escape detection, but that if it passes in the reverse direction it will be recorded. Consider, first, the passage in the direction *AB*, the following conditions occur—

(1) *T* dark, *G* illuminated. Contacts L_1 open.

(2) *T* dark, *G* dark. Contacts M_1 close, but *P* is not energized since L_1 is open.

(3) *T* illuminated, *G* dark. Contacts L_1 close, but *P* is not operated, as there is now no current in the circuit *RLK*.

(4) *T* illuminated, *G* illuminated. Original conditions restored.

In neither case has the recorder been operated. Now consider the direction *BA* : the following conditions occur—

(1) *G* dark, *T* illuminated. Contacts M_1 close.

(2) *G* and *T* both dark. Current flows in the anode circuit of valve *T*. Most of the current flows through the path RL_1M_1PK since this is of low resistance compared with the coil *L*. Hence, *L* is not energized and contacts L_1 remain closed. Current then flows through *P* and actuates the indicator contacts P_1.

(3) *G* illuminated, *T* dark. Contacts M_1 open, thus releasing the coil *P*.

(4) *G* and *T* illuminated. Original conditions restored.

In the second state the indicator has been operated, showing that the arrangement records in the direction *BA*, but not in the direction *AB*:

Multiple Recording.

Quite a simple device can be constructed to indicate the *n*th interruption of the beam of light. If *n* is small, say, of the order of 25 or less, the relay can be arranged to move a toothed wheel by means of a pawl, each time the relay is energized the wheel being rotated a distance equal to the space of one tooth. Opposite one tooth is a small hole which in one position only of the wheel allows light from a lamp to fall directly on to another photocell and indicate by means of a recorder or alarm the *n*th operation of the relay.

For larger values of *n*, the relay can mechanically operate a small shaft on which is keyed a gear wheel with wide teeth. A secondary shaft, on which are several gear wheels having p, q, r . . . teeth respectively, is fixed to mesh with the primary shaft. It is clear that if each of the wheels has one perforation, alignment of the holes will occur once after every *n* revolutions where *n* is the lowest common multiple of p, q, r . . . Obviously, by making p, q, r . . . prime numbers of higher values and increasing the number of wheels, *n* can be made many millions. This case will be useful where the primary shaft is mechanically and not photoelectrically operated as in the case of high-speed rotating machinery.

Racing.

Not the least important use of the photocell as a recorder is that in which it is employed for the automatic timing of races. In timing by hand it not infrequently happens that there is some discrepancy between the times of the judges of which there are usually several. This is, of course, due to the human element and the difficulty of recording intervals of time to a hundredth of a second under such conditions.

The photoelectric device rules out the human element, and while it is obvious that no recording instrument can be instantaneous in operation, it is claimed that the photocell recording is far superior to hand timing. In addition, the time lag of the instrument can always be measured, and as this is constant, a correction can be applied accordingly.

Fig. 26 shows an illustration of the Osram photocell amplifier on a racing track. The exciting lamp is housed at one side of the track and the photocell amplifier at the other side on the finishing line. A cylindrical tube is fitted over the aperture covering the photocell in the amplifier, so that the apparatus is not affected by changes in daylight and only operates by interruption of the direct beam from the lamp. As soon as the beam of light is interrupted by the passage of the winning animal across the finishing line, the photocell relay, which controls the timing clock in the judges' box, actuates the mechanism which stops the clock, and the time of the winner can then be read at leisure.

In apparatus of this type it is frequently desirable to arrange the relay so that as soon as it operates, the contacts are locked together until released by an independent control. The successful operation of the apparatus does not then depend on the momentary contact of the spring of the relay and the movement is positive in action.

Fig. 27A shows diagrammatically a suitable control board which is housed in the judges' box and which comprises the clock, the face of which is illuminated by a small lamp, and the switches controlling the photocell equipment, resetter, etc.

Fig. 27B shows the modification of the standard amplifier circuit. It will be noted that as soon as the relay coil is energized, which is only possible when switch *M* is closed, contacts *L* open and the photocell is switched out of circuit and the set is no longer sensitive to light. At the same time the clock *T* is operated by the closing of contacts *P*. As soon as contacts *L* open, the normal anode circuit

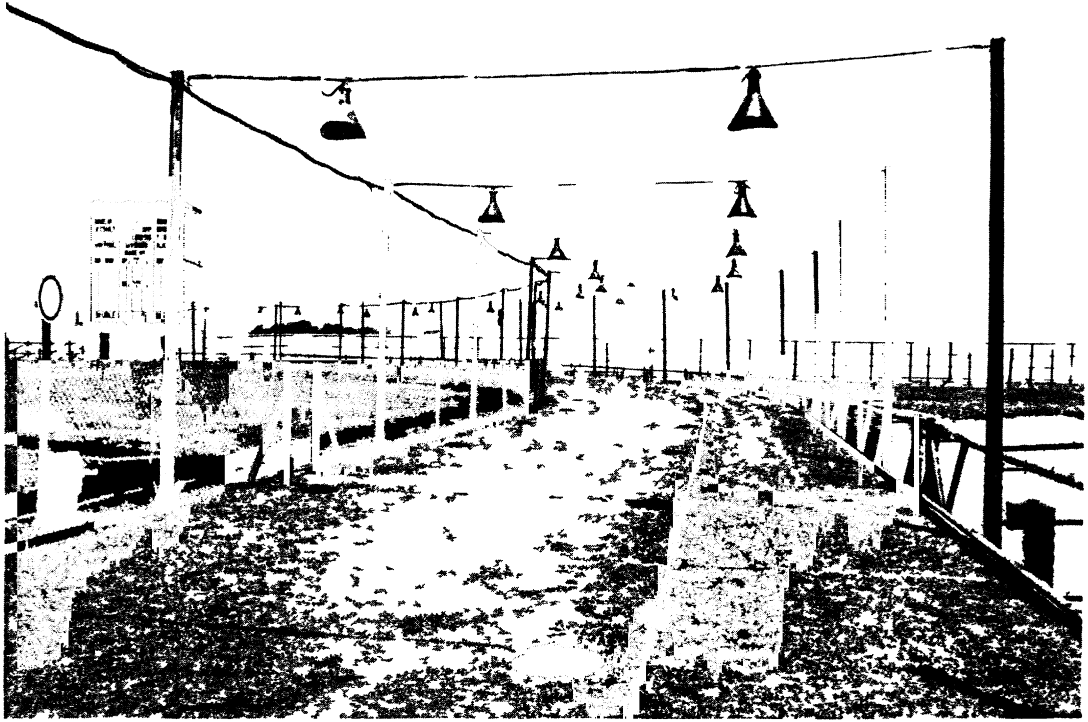


FIG 26 RACING TRACK INSTALLATION

of the valve holds the contacts in this position until *M* is opened, when they revert to their original position. In this way only the first interruption of the beam of light affects the clock, and the passage across the finishing line of the second, third, and succeeding competitors does not upset the setting of the time registered by the first. The clock incorporates an additional safety device *Y* in the form of a small button on which is engraved an arrow. A similar arrow is also engraved on the case, and the button actuates a spring contact inside the case so arranged that before the clock can start, stop, or reset, *Y* must be depressed by hand except when the arrows are in line. This forms an additional safeguard against stoppage by accidental contact with the controls on the part of the judge. Fig. 27B shows the internal wiring of the control panel.

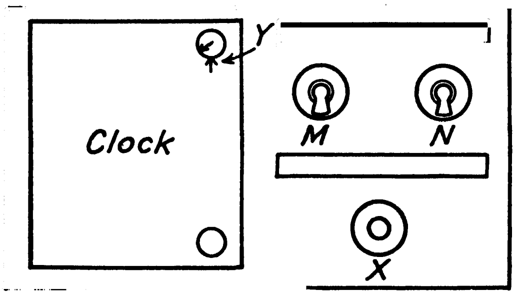


Fig. 27A. Diagrammatic Sketch of Control Board Switches and Clock

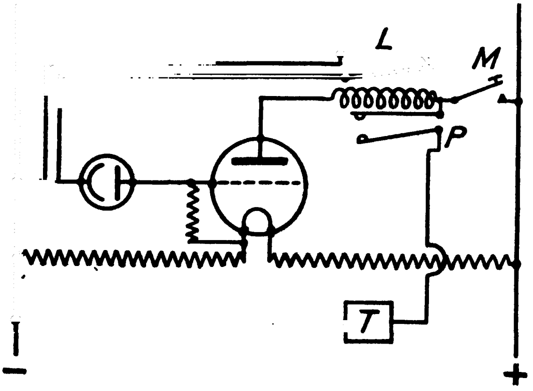


Fig. 27B. Circuit Diagram for Clock Operation

The clock is normally started by a mechanically-operated contact which, in the case of greyhound racing, may take the form of a "push-to-break" contact. This is attached to the side of the trap and held open by a small projecting arm on the trap door. As soon as the trap door is raised the contact closes and the clock starts.

The sequence of operations during a race is as follows, the switch being off—

As soon as the trap opens the clock starts. Switch *M* is closed just before the finish of the last lap, when the first interruption will stop the clock. As soon as the clock has been read, *M* is switched off and, pressing push-button *X*, brings the clock back to zero.

If, by accident, the controls are operated in the wrong order, the clock can always be reset by alternately depressing *X* and *Y*, *M* being switched off.

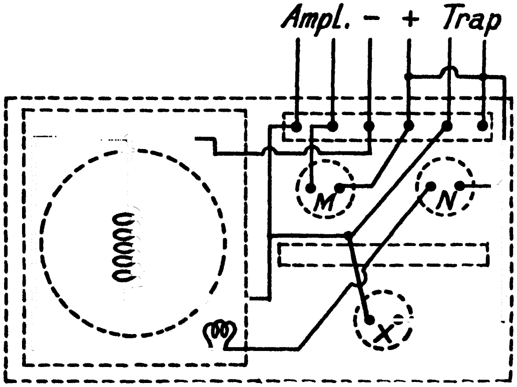


FIG. 27C. INTERNAL WIRING OF CONTROL BOARD

The equipment, of course, operates from supply mains D.C. or A.C. with slight modification.

A Method of Measuring the Speed of Rotation of Shafts.

An ingenious application of photoelectric cells to laboratory work, and one which will appeal to the engineer, has been developed in connection with a new method of measuring the speed of rotation of shafts.

It is required to measure the speed and performance of rotating discs in some experiments, during which the vibrations of a disc are being examined and recorded on an oscillograph. An extra disc is attached to the shaft which has segments of reflecting surfaces on its periphery. These segments are of different lengths and areas so that they can be easily recognized.

A beam of light is directed on the edge of this disc, and the light intermittently reflected on to a photocell The resulting current is amplified and a record obtained on the oscillograph in parallel with the other records No slit is used in the optical system, as the image

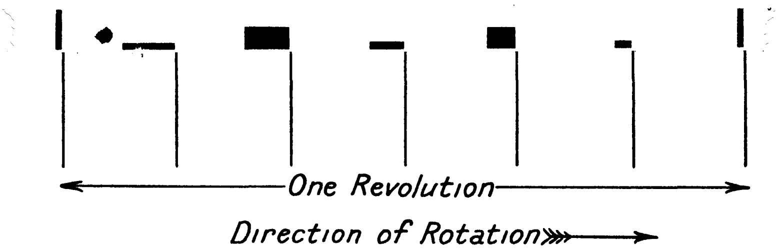


FIG 28A INDICATOR FOR ROTATING SHAFTS

of the lamp filament is very small in comparison with the length of the segments

A photocell method has been adopted because no difficulty is experienced with bad contacts no adjustment for wear is required and no inaccuracies from worn contacts or brushes need be expected

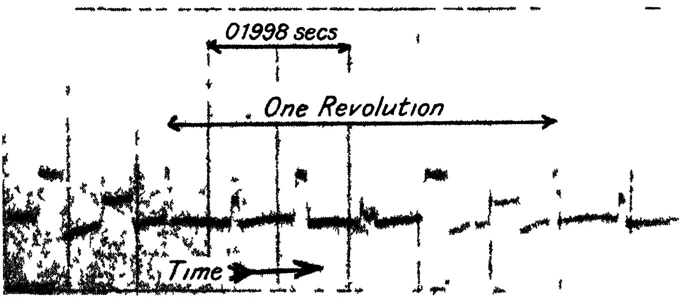


FIG 28B INDICATOR FOR ROTATING SHAFTS

Since it is necessary to be able to observe the vibrations of the disc in different sections while revolving at high speed the segments on the auxiliary disc are made of varying lengths so that the reproduction on the record enables the particular section to be recognized quickly

A typical record is given in Fig 28B, and it is interesting to compare this photographic record from the oscillograph with the actual shapes of the segments, which are illustrated in Fig 28A

Such an arrangement proves useful in cases of a similar nature where it is desirable to eliminate rubbing contacts

CHAPTER IV

ALARMS, INDICATORS, AND SAFETY DEVICES

As an indicator devoid of inertia, requiring no contacts electrical or mechanical, combined with reliability of operation, the photocell naturally appeals to industrial engineers. It is their interest and co-operation that has enabled so rapid a development of its uses in safety devices to take place, and it is these advances we propose to describe briefly in this chapter.

Naturally, the first consideration of safety concerns the photoelectric apparatus itself. If this can be made to protect itself automatically against any form of failure, it is obviously in a favourable position to ensure safety in other devices. We have to consider then the behaviour of the amplifier in the event of a failure of one of the components, namely, the valve or illuminating lamp, both of which have a definite life, during the operating period. It is frequently necessary to ensure that should such failure take place some indication of the fact will be given either by the circuit itself signalling to the "alarm" or "indicator" position, or by the inclusion of a simple external device enabling it to do so. In the circuit shown in Fig. 12, it is assumed that the condition of darkness is that which operates the indicator during normal working as, for instance, in the case of counting moving objects which interrupt the beam. In this case, any failure of the lamp or its connections is announced by a signal coming on continuously at the wrong time. Under these circumstances, therefore, no additional apparatus is necessary to provide against lamp failure. If, however, during normal working the condition of light on the cell operates the indicator, i.e. in the case of detecting a fracture in a strip of moving paper, the extinction of the lamp can be provided for by an extra relay in the lamp circuit, this relay being closed as long as the lamp circuit is intact, and the "open" contacts in parallel with those on the anode relay controlling the indicator.

To guard against failure of operation due to filament fracture, either the circuit of Fig. 12, or that of Fig. 10, must be used according as light or darkness normally operates the indicator. There is, however, another convenient method of securing protection against this failure, by using a four electrode valve. By including a relay in the inner grid circuit, a safety device is provided which will operate if the filament circuit is not normal. The excitation of this relay is independent of the position of the anode relay, and it is energized as long as the filament emission of the valve is normal. Its external contacts should be connected in parallel with that pair of the main relay which operate the indicator. This arrangement can, therefore, by a change in connections on the main relay, make the safety position correspond to either light or darkness on the photocell.

Fig. 29 shows the connections of the four electrode valve as used in Fig. 12. There are other methods of securing the conditions stated above, but they are, in general, less effective and more complicated, and will, therefore, not be discussed here.

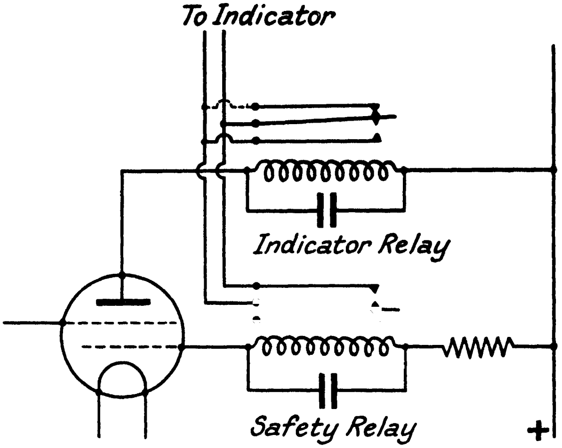


FIG. 29 FOUR ELECTRODE VALVE PROTECTION CIRCUIT

Danger Alarm.

A very simple protective device is that in which the standard unit is fitted as a guard on power presses. The light beam is arranged to pass across the dies on to the photocell unit, and the latter disconnects the power drive if obstruction of the light occurs. The operators are, therefore, protected against damage to their hands if they accidentally touch the dies while the machine is in operation. Similarly, protection can be secured in lift gates which can be designed to close only after a specified period has elapsed since the last person passed in or out.

Foremost among the simpler cases of alarms is the invisible ray burglar alarm. In this, as in all other forms of alarm, the chief merit is the extent to which it is foolproof or capable of escaping detection. No claim can be made that such an arrangement is completely infallible, but it can be made as efficient as any other alarm, and certainly more difficult to discover. In consequence, it is to a large extent as much a preventative as a cure. The exciting source of illumination will, in general, need to be obscured both by means of opaque filters (cf , p 37) and by building the lamp house into some portion of the structure so that its presence is not obvious on inspection

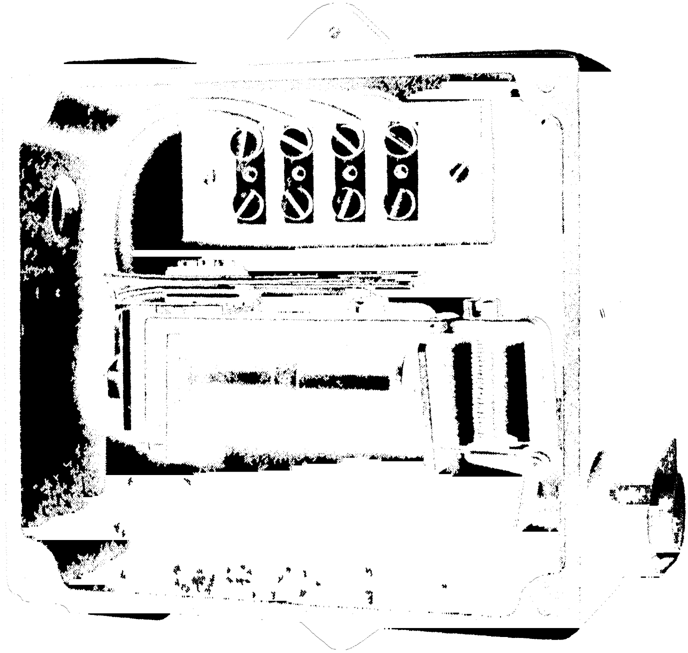


FIG 30 SELF-LOCKING RELAY
(*General Electric Co , Ltd*)

In nearly all cases it is desirable to arrange the alarm so that when the light beam is once interrupted the bell will continue to ring until reset by some independent switch. Accordingly, the circuit shown in Fig. 27B, can be conveniently employed, the switch being a push which, when operated, resets the circuit.

Alternatively, a self-locking form of relay can be used, this being another slight modification of the type already described. Fig. 30 shows a photograph of such a modified relay with the cover removed. The armature is slotted, and when the coil is energized, a pawl engages with the bottom of the slot, holding the armature close to the core, and remaining in this position even when the coil ceases to be energized until lifted by the bell crank. This crank is actuated by the push button on the right-hand side of the case. The downward pressure of the spring contacts is sufficient to restore the armature to the OFF position.

Multiple Point Alarm.

Another alternative, and one which permits of easy testing inasmuch as the last person leaving the protected building can be assured that the system is in perfect working order, is that shown in Fig. 31. This relay consists of the usual electromagnet *A*, and armature pivoted at one end *B*. Immediately beneath this armature is a pawl *C*, which can be lifted by pressing in the plunger *D* from outside. When the pawl is raised, it engages with a small projection on the armature and is retained in the position shown by the dotted lines. In this position, but not in the down position, the armature is within the field of attraction of the relay coils *A* when the latter are energized. As soon as any one of the relay contacts *F*, which are all in series, is opened by the interruption of one of the invisible rays, the coil circuit is broken and the relay armature drops into the position shown, which closes the bell circuit and rings the alarm. The bell continues to ring until the plunger *D* is pushed in. This plunger will raise the armature into the position shown by the dotted lines. If all the contacts are now closed and everything in order, the relay coils will be energized and pull the armature up. *C* will fall back into the horizontal position, and the resetting will be complete. If not, there is either an open contact or the circuit is at fault somewhere, and this will be indicated by the tell-tale buzzer, the circuit of which is made through the frame of the relay and the pawl, as shown. As soon as the relay is reset, therefore, the buzzer circuit is disconnected, provided everything is in order. Should the buzzer continue to sound after the last contact has been closed and the plunger pressed in, some point of the alarm circuit is at fault.

Fig. 32 shows an elaboration of the apparatus just described suitable for adapting to cases where a number of points have to be protected. This could be used as a basis for the design of complete burglar alarm installations. It will be noted that the valves have their filaments connected in series, it being preferable, other things being equal, to use 2-volt valves if any number of points are under consideration, so that the difference between the anode-filament potential of the first valve and the last one is a minimum. Each photocell and its valve, as previously recommended, are mounted together, and the cathodes taken out to one common negative lead. In Fig. 32 separate cathode leads are taken to the switches *P* which are all normally closed. These switches enable each point to be tested in turn, as by opening any one of them the corresponding photocell is cut out and the anode relay energized. The circuit shown has one common anode relay, the spring contacts of which can, if desired, be used in conjunction with a set of the actual "push-to-break" contacts forming a closed circuit system operating a drop relay of the type previously described. The closed circuit supply can, of course, be fed from a battery or low tension side of a step-down transformer.

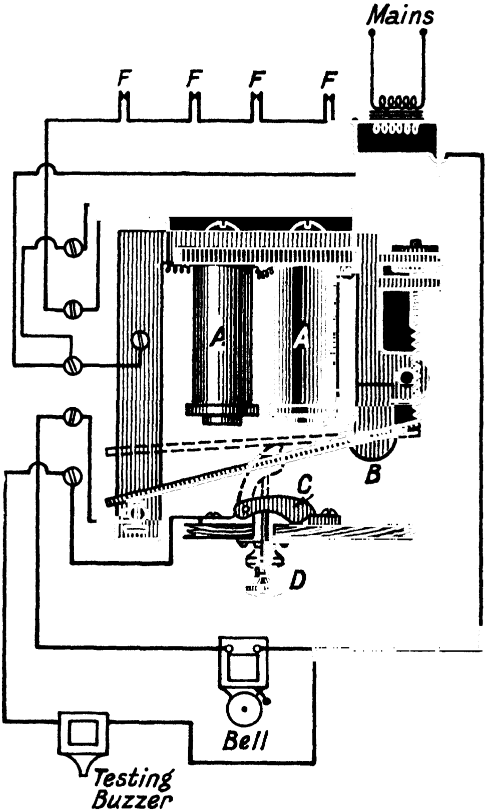


FIG. 31. MULTIPLE ALARM TESTING RELAY

It should be noted in connection with running valves in series that battery type valves, which would in almost every case be used from considerations of current consumption, are rated on voltage and not current readings, and it is therefore necessary either to select valves for series operation, which is preferable though not always possible, or by means of the resistances installed, to under-run them all considerably so that a safe margin is secured. As the circuit will operate quite well with much less than the full emission, such procedure is usually quite satisfactory.

Another point to bear in mind is that in the quiescent state there is no anode current in any of the valve circuits. Had the normal state been that in which anode current was flowing, it is clear that the filament of any one of the valves would carry not only its normal filament current but also the plate current of all the valves to the left of it (Fig. 32). Consequently it would be essential to limit the plate current of each valve, by grid bias, to the safe minimum required to operate the relay so as to prevent over-running some of the filaments, and there would also obviously be a limit to the number of valves which could be run successfully in series. Such a case would occur if the circuit of Fig. 10 were used in preference to that shown in Fig. 32.

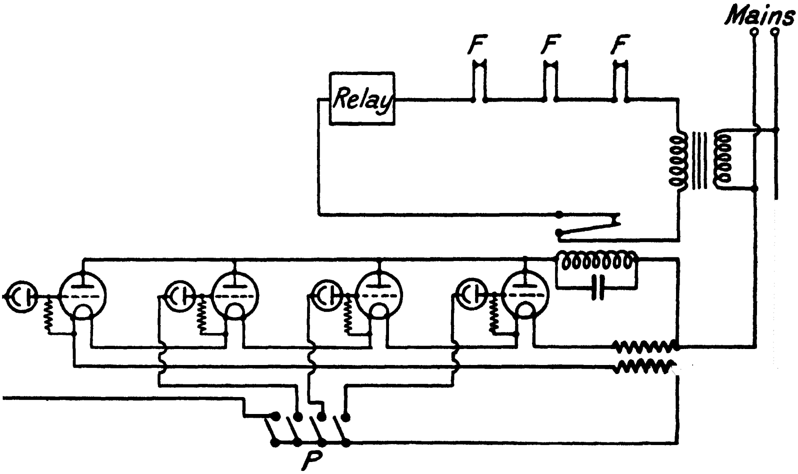


FIG 32. MULTIPLE POINT ALARM CIRCUIT

For the purpose of providing further precaution against valve filament failure, the four electrode valve, with an extra relay, could be incorporated in the circuit shown in Fig. 32 with a slight additional complication. There is, however, some difference of opinion as to whether the alarm should be put in operation by the failure of any portion of the circuit, or whether a test from a centralized point, such as is shown in Fig. 32, before setting the alarm should be sufficient.

There is no doubt that great inconvenience and expense is incurred by the alarm coming into operation when a lamp fails in the case of an extensive building where a periodic test would be sufficient. However, the precise arrangement is largely a matter for consideration and has to be decided upon by the merits of the particular case and the personal opinions of those for whom the installation is being carried out.

Another important factor meriting attention in such an installation is the type of lighting equipment to install. As previously mentioned in Chapter II, the most suitable type of illumination is the small automobile headlamp of 12 volt or lower rating.

If A.C. supply is available and the points of installation few, it is generally best to operate the lamp from separate transformers unless the points are fairly close together, when they can be burnt in series or parallel from one transformer. As the current of such lamps will be fairly high, it is desirable not to separate the lamp from its transformer by too great a distance, owing to the drop in voltage along the cables, as there is obviously a limit to the size of cables used on a protective installation.

If the number of points is larger, it is possible to run all the lamps in series and to select lamps of a voltage which is nearly a submultiple of the mains voltage. Drop of voltage in the cable will ensure that the lamps are not over-run and that adequate life is secured.

The remarks previously made concerning series operation of valve filaments apply equally well to the case of the lamps which can be used in series, irrespective of the nature of the electric supply. There is no really satisfactory method of operating a few low voltage lamps from a direct current supply.

Fortunately the days of D.C. supplies are numbered, so that the difficulty will in time disappear, but for a few more years this type of supply will remain a thorn in the engineers' side.

It should be noted that in Fig. 32 the failure of any lamp will operate the alarm. Lamp manufacturers will supply particulars of the probable life under specified conditions, and it is preferable to replace the lamps as soon as this period is reached rather than attempt to economize by using them longer, and at the same time enormously increase the possibility of trouble through false alarms.

Tell-tales.

Another useful protective device consists of an arrangement by which the lights of a shop, bank, warehouse, or store can be switched on from the outside by means of a torch. A policeman is thus enabled to look into the building to see whether everything is in order during the night. For positive action it is usually best to incorporate in the amplifier a time delay switch similar to that described on page 76, and to install the set in such a way that it is neither easy to detect nor operable by any other than the correct authority.

The photocell can be covered by a small plate which is automatically locked when closed, and can be opened only by a special key. This prevents the equipment from receiving attention from inquisitively inclined persons and youthful observers who delight in seeing things "work."

Gas Detection.

Danger in the form of poisonous gas is also easily dealt with automatically by the aid of the photocell. For this purpose a bridge circuit using two photocells, which actually constitutes a modification of the simple circuit shown in Fig. 11, can be very conveniently employed, and forms the basis of the Pritchard gas detector.

The apparatus can be made up in a form suitable for use in such places as coal mines, shafts, ship-holds, etc., where the presence of noxious gas should be made apparent. Actually, the circuit shown in Fig. 33 operates in principle in precisely the same way as its simpler counterpart—the one-cell circuit—except that in this case the grid of the valve becomes negative where the amount of light reaching the cathode of cell *C* is greater than that reaching the cathode of cell *D*. If the reverse condition exists then it is clear that the grid is positively charged and the anode current unaffected. The operation of the relay depends essentially then upon the change in illumination of cell *C*, and as soon as this exceeds that of *D* the relay is actuated.

A common source of illumination is used for the two cells, so that change of illumination due to small voltage changes on the lamp produces no effect on the final result. Vacuum cells are usually employed to ensure constancy of operation, and it is desirable to fit each with a movable diaphragm to facilitate preliminary adjustments. It is clear then that to adapt the arrangement for automatic gas detection the cathode of the cell *D* must be covered with a transparent thin-walled vessel placed in the direct beam from the lamp and containing a chemical indicator which is subjected continuously to the action of the gas under observation. This indicator must be of such a nature that its reaction with the impurity it is desired to detect will bring about a change in its optical transparency. It is possible by calibrating the apparatus, by setting the diaphragms and treating the indicator with a known amount of impurity, to secure quantitative measurements of fair accuracy.

The apparatus outlined above can, of course, be operated from supply mains, but in order to render the equipment accurate in the reproduction of results it is desirable at least to work the photoelectric portion of the equipment from batteries, and the whole equipment can then be readily produced in the form of a small self-contained portable unit. The operation of the lamp from a battery would necessarily be troublesome in upkeep, and as variations in the light source are provided for, this can be a standard lamp or a low voltage lamp operated through a step-down transformer for A.C. supplies. Similarly, the valve can be one of the indirectly heated mains type fed in the same manner from a step-down transformer. The gas under observation is drawn through the vessel containing the indicator either automatically by means of a small motor pump, or by one hand operated. The intake should extend to the bottom of the vessel, and horizontal baffle plates should be fitted to break up any large bubbles rising to the surface of the liquid which might otherwise upset the equilibrium of the apparatus by passing directly through the light beam. Alternatively, this can be prevented by fine adjustment of the suction of the motor pump.

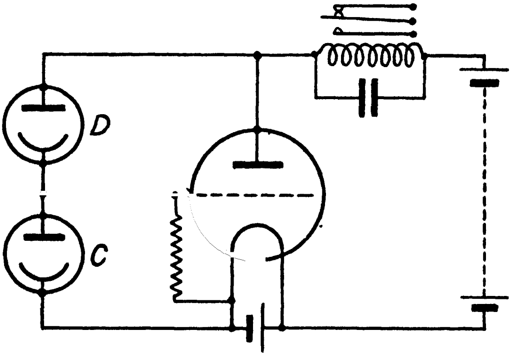


FIG. 33. TWO-CELL CIRCUIT

The nature of the indicator will depend on the impurity it is desired to detect and, in general, should be affected only by this impurity and not by others inadvertently mixed with it, a condition which is frequently not easy to obtain, especially in the case of the more delicate reactions. Carbon monoxide, which so frequently occurs as a product of incomplete combustion, is detected in relatively large quantities by the black precipitate thrown down from an ammoniacal solution of silver hydroxide or by the colour change which takes place in an acid solution of weak potassium permanganate. Traces of carbon monoxide are detected by a solution of palladium chloride in water acidified with dilute hydrochloric acid. Unfortunately, this reaction is not characteristic; ammonia, acetylene and hydrogen sulphide giving the same results. Similarly, chlorine may be detected with silver nitrate solution, sulphur dioxide with potassium chromate—an instance which should be useful in refrigerating apparatus; in fact any gas, with the exception of those chemically inert, can be detected by this means, as the apparatus is extremely simple and easy to handle, involving nothing more than switching on the current and filling the containing vessel with the required reagent.

Instances of the utility of this apparatus could be elaborated almost indefinitely. It has, of course, been argued that the colour changes upon which the indicators depend could be recorded equally well by visible detection, but it is obvious that if means are provided for automatically changing the reagent after detection, a mechanical arrangement could be easily devised to give a continuous record which would be entirely independent of the human element. In addition to this advantage, colour changes in the reactions, which are too feeble to be easily detected by the eye, can be detected photoelectrically, and thus a great deal of uncertainty can be avoided.

In many cases the alarm circuit would consist of a buzzer or bell, but could be extended to include an electric fan to reduce or disperse the gas containing the impurity when the latter reached the danger limit indicated by the photocells.

The use of such a corrective device at once leads to the obvious conclusion that the arrangement has uses in connection with automatic titration or the treatment of water with chlorine for sterilization, alkali for reducing acidity, or lime for softening. This particular application has been used in automatic water purifiers, and is the subject of British Patent No. 348,654. Orthotolidene is used as an indicator, the yellow colour produced being indicative of the amount of free chlorine present and, consequently, a guide as to the amount of organic matter originally present in the water. The colour developed by the addition of the indicator can, by means of a suitable diaphragm adjustment over the aperture of one cell, at a certain depth, be made to operate a valve which will increase or reduce the amount of chlorine added to the sample withdrawn from the main water supply. In this way, by means of an auxiliary mechanism which makes the treatment periodic, the dosage can be controlled within fairly narrow limits. This is a representative example of the utility of the two-cell circuit, but a little reflection will indicate that it has wide possibilities in many other directions. It must, however, be remembered that the operation of the circuit depends not on the amount of light reaching the cells, but on the difference in the amount of light reaching one cell relative to that reaching the other cell. The sensitivity of the set is therefore materially increased by a suitable choice of cells.

To be most effective the cell should have maximum sensitivity to the rays absorbed by the reagent when the reaction takes place, so that the change of cathode illumination during the reaction is as great as possible. In this connection a strong solution may require a different cell combination from a weak solution of the same liquid, depending entirely upon the selective absorption of the sample. This information can be accurately determined with the spectroscope, but a trial is the quickest method of choosing the right combination.

Smoke Detection.

A good deal of attention has been paid in recent years to the abatement of the smoke nuisance, which is still all too prevalent in industrial areas where inefficient combustion of fuel is taking place on a large scale. This nuisance is, amongst other ills, responsible for the production of fog and mist which is of such frequent occurrence in autumn and winter.

The gradual process of electrification has accomplished much towards reducing this trouble, but a great deal remains to be done. It seems probable that some form of smoke recorder, such as can be provided very suitably by photoelectric apparatus, together with a means of removing unconsumed particles, say, by electrical precipitation will, in future, form part of the equipment of every large industrial fuel consuming plant.

It is clear at the outset that "smoke detection" may include those detectors which merely indicate the presence of smoke as a forerunner of the more serious occurrence of a fire, those which give an alarm when the smoke in a certain process or position exceeds a predetermined density, or those which produce a periodic or continuous chart record, showing the extent of atmospheric pollution due to unburnt combustible particles ejected from a flue. The former usually require very simple photoelectric apparatus similar to that described in the previous pages.

Fig. 34 shows an illustration of a typical installation placed in the ceiling of a warehouse merely as a detector. The photoelectric fire alarm has several obvious advantages over systems employing temperature rise for their operation, such as fusible plug sprinklers. With the latter there is always a considerable time before the heat is sufficient to operate such devices, and in nearly all cases a great deal of smoke is produced long before the thermal devices operate. In addition, sprinklers have a nasty habit of leaking, much to the discomfort of the occupants of the building where installed. An extensive installation can be designed on similar lines to that previously outlined for burglar alarms, and a central indicator used to register the exact position of the fire in any part of a building. The equipment is therefore ideal for warehouses, stores, factories, hotels, and similar institutions

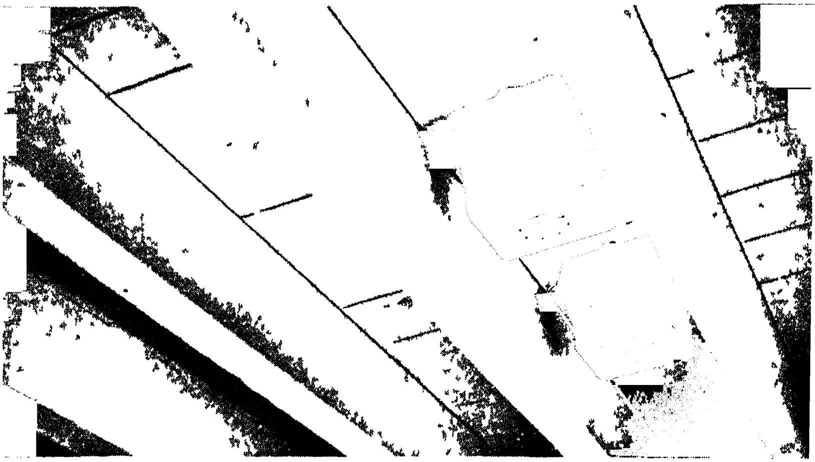


FIG 34 FIRE ALARM

(*Burovox, Ltd*)

Cases sometimes arise, for instance, in the holds of cargo boats where some trouble may be experienced owing to the obscuring of the lamp by exposure to foul atmosphere, or the presence of insects, etc., especially in tropical climates. In such cases it may be desirable to dispense with a lamp and devise some other means of operation. One system which is being developed consists of exhausting through tubes converging to a central point on the ship, air being drawn from all the vulnerable points of the hold in turn and passed through a detector similar to that just described. This accomplishes the same result and also enables a rapid location of the fire to be made. Normally such difficulties would not occur, as it is possible to inspect and clean periodically the exciting lamps.

The recording requirement is more elaborate, for while it should be noted that in the latter case such a record is not in itself an indication of the efficiency of combustion, the presence of smoke in a factory flue always indicates inefficient combustion. At the same time the absence of smoke may not be an indication of efficiency. Excess of air admitted by opening the dampers will always reduce the density of the smoke by dilution with air and consequent reduction of flue temperature. A smoke recorder should therefore be an accessory to, and not a substitute for the usual CO_2 and temperature recorders.

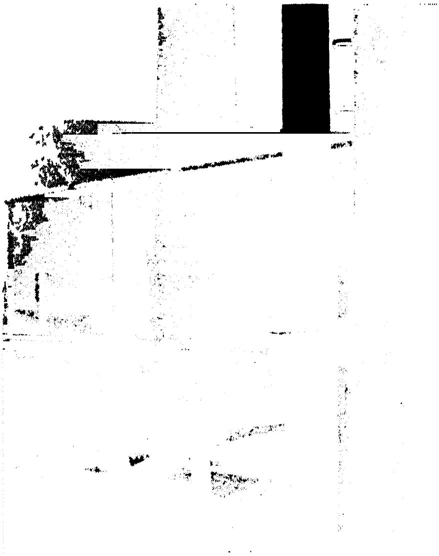


FIG. 35A. PHOTOCELL UNIT ON A FACTORY CHIMNEY (SMOKE RECORDER)

The successful operation of a recording smoke density meter presents several other difficulties which have to be overcome before a reliable chart can be obtained. It must be remembered that a 1 per cent change in voltage applied to a gasfilled lamp results in a 6 per cent change in light output, so that with the voltage variations met with in municipal and company supplies a change of 30-40 per cent in illumination, incredible though it may seem, is by no means uncommon. It is clear then that any mains-operated lamp will, in the absence of smoke passing between it and the recording photocell, merely produce a chart record of the mains voltage variation, or, with smoke passing, this record superimposed upon the smoke density record.

Several alternatives are obviously available for meeting the difficulty. They are—

(1) A motor generator with constant voltage output for operating lamp.

(2) Accumulators for the lamp.

(3) Balanced cell circuits, and

(4) Barretters.

(1) and (2) are costly in outlay and troublesome in upkeep, although in most factories there are means available for charging accumulators for other purposes; (3) is theoretically the ideal method, but for quantitative measurements tends to become unstable owing to small changes in the cells used. On the whole, the barretter is the most satisfactory, though not the complete corrective device. It consists of an iron wire filament in a gas of high thermal conductivity such as hydrogen or helium, the essential property of the barretter being a high positive temperature coefficient of resistance. Operated in series with a power consuming device, the barretter will maintain a constant current in the circuit over a limited range of voltage variation, the range of variation being determined by the design of the particular barretter used.

FIG. 35B. THE LIGHT UNIT WITH ADJUSTING METER (SMOKE RECORDER)

Other materials than those mentioned have been used in the

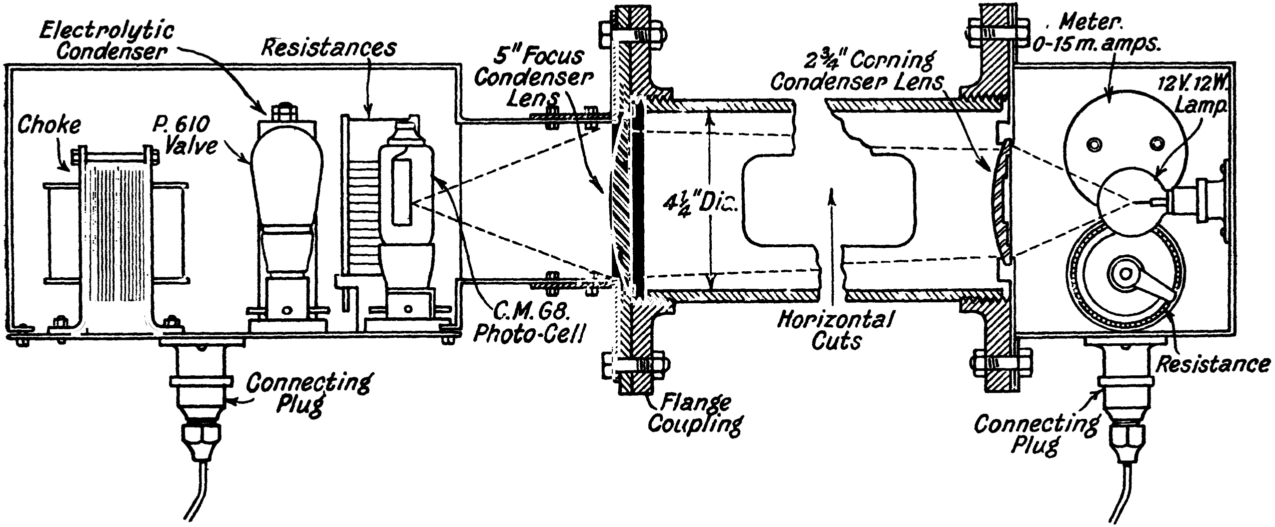


Fig. 35c. Lay-out of Apparatus in Smoke Recorder

construction of such a device but with less success as regards the degree of current control. It might be supposed that the use of a barretter would prove unsuccessful in preventing a record being made of the light variation as, obviously, it is a corrective and not a preventative, and the change in voltage must take place before it can be corrected. This is to some extent true, but it must be remembered that the voltage changes likely to occur take place relatively slowly and current control is fairly close.

Fig. 35C shows a diagrammatic sketch of suitable smoke recording equipment, A steel tube passes right through the chimney shaft and the light and photocell units are bolted to flanges at either end. Two long horizontal slits are cut in the pipe through which the smoke passes. With this arrangement the apparatus is kept rigid and in correct optical alignment. Illustrations are also given of the apparatus.

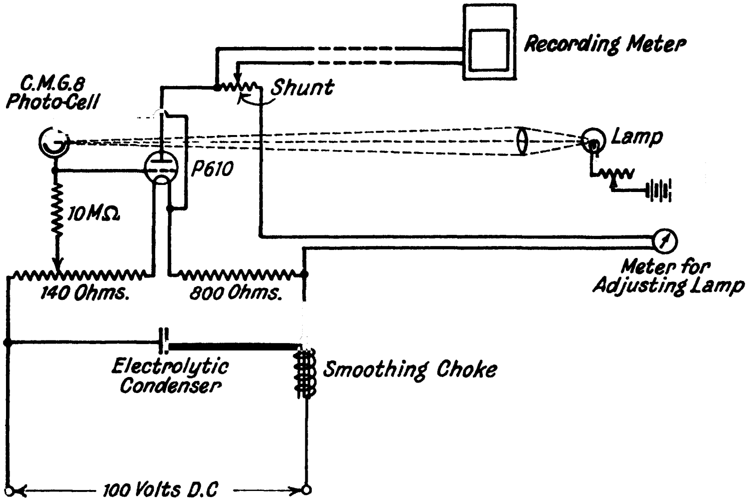


FIG. 36. CIRCUIT DIAGRAM OF SMOKE RECORDER

Other smoke detectors have been produced in which samples of smoke are drawn out of the flue by a fan and passed into a small box containing the lamp and cell unit, but these do not give a true approximation to the density of the smoke in the main flue.

Fig. 36 shows the circuit used in this experimental equipment. The chart record is made on a Cambridge recording millivoltmeter, and thus the record is to an accuracy higher than would be generally required since it is usual to measure smoke on the Ringelman scale of densities, which consists of three grades of absorption between on smoke and black smoke corresponding respectively to zero, 25 per cent, 50 per cent, 75 per cent, 100 per cent light absorption. Thus it is proposed to dispense with the expensive recorder and substitute a series of relays in the anode circuit of the valve, which will operate selectively at the currents corresponding to the densities on the Ringelman scale and so obtain a record in density steps instead of a continuous line chart. The photocell is shown operating at a voltage of 20, and is of the vacuum type. Theoretically, the potassium cell is most suitable, as the finely divided particles of smoke absorb more of the shorter visible wavelengths. In practice, however, trouble is likely to occur in the cell owing to exposure to heat (by which the caesium cell is much less affected). This and other considerations of reliability have led to the adoption of the C.M.G.8 type of cell. For A.C. supply operation, the chokes and condenser shown are not necessary, and the circuit becomes normal. The illuminant is here shown fed from a battery, but in the case of A.C. supplies a low voltage lamp and step-down transformer is the most satisfactory arrangement, and one which still further assists the voltage correction of the barretter.

Occasionally, trouble may be experienced from fouling of the glass windows by the soot deposited on the inside. Obviously, the simplest method is to clean the glasses daily, but in cases where this is not permissible the arrangement shown in Fig. 36 has proved quite effective. A small variable resistance is placed in series with the lamp, and a direct reading meter in the anode circuit of the valve and in series

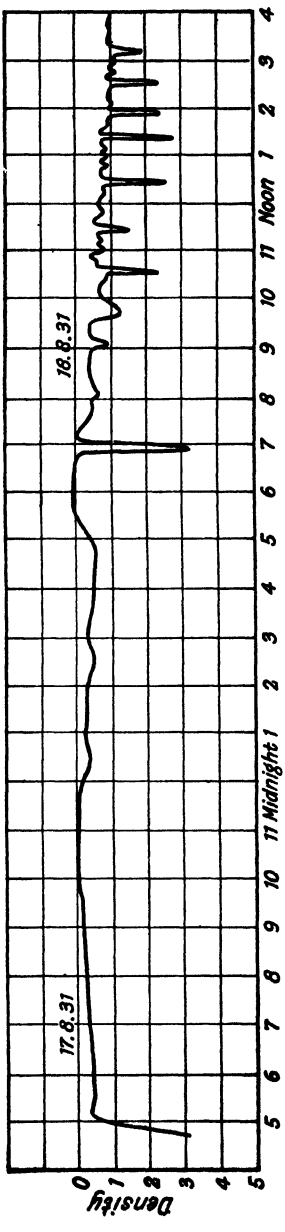


Fig. 37. Chart from Smoke Recorder

with the recorder. This meter has a clear scale with one mark to which adjustment should be made for no smoke passing in the shaft. When the chimney is clear and the daily renewal of the chart made, the resistance is adjusted until the needle is upon this mark. The equipment is then adjusted for a day's operation, and a correction applied for any deposit accumulated during the previous 24 hours. When the glasses require cleaning, this fact is indicated by the position of the rheostat, all the resistance being out and no further adjustment possible. In this way removal of the glass windows more frequently than once in every month or six weeks is avoided.

Fig. 37 shows a typical chart record. The intervals at which appreciable smoke is emitted are clearly shown. The slight variation between the 0–1 density during the night period represents the general drift due to slight uncorrected errors, which it is clear are insufficient to have much effect on the general record.

Miscellaneous Cases.

It is proposed to conclude this chapter with a brief outline of one or two practical instances where the photocell has been used as an indicator or alarm in an industrial undertaking.

Mention may be made first of a multi-point control on the rolling machine of one of the largest paper-making machines in the world. Two lamps are arranged on one side of the machine above the level of the paper to send a beam of light one across each edge of the sheet of paper. This paper is delivered from the rollers at a rate of about 200 feet per minute, the photocell and valve being on the other side of the machine and below the normal level of the paper. A break in the paper in such a large machine, if not observed instantly, results in an almost hopeless jamb of paper and a considerable wastage of time in extricating the waste material and refeeding the new sheet on to the rollers. With photocell protection a break at either edge of the paper, in which position the first rupture always starts, immediately gives the alarm and also sets in motion an arrangement which cuts a clean edge across the fracture and facilitates restarting the machine. In this case the photocell is normally dark, so that the precautions and limitations of series operation of valves mentioned on p. 53, are operative. In this particular installation elaborate means are provided on a centralized switchboard for periodically ascertaining that the valves and circuits are functioning satisfactorily.

Incidentally, whilst on the subject of paper-making, passing reference may be made to the application of the photocell in the printing of paper bags. From various technical considerations which the process of manufacture involves, it is desirable to print the advertising matter, which finally appears on the side of the bag, on the paper while it is in the form of a roll, and it is essential therefore that when cut up into sections the printing shall be evenly spaced. Normally, there is a tendency for the paper either to stretch or contract after printing, so that after a few cuttings have been made from the roll the printing matter will appear to be eccentrically placed. To avoid this, a small opaque mark on the edge of the paper in a fixed position relative to the printing interrupts the light on to a photocell, by which action the cutting mechanism is set in motion. If, owing to stretching or contraction, the normal position of this spot becomes altered, the machine is automatically speeded up or retarded as the case may be, thus applying the necessary adjustment. The principle of action of such an arrangement should be clear to the reader, the details not being described, being purely mechanical.

Another interesting and useful though quite simple industrial use is exemplified in the recent installation for checking coupons in connection with the packing machines of a large factory. Gift coupons which are enclosed in packets of chocolate are picked up by a suction plate attached to an oscillating arm on the machine, and are released one at a time when the arm is in its lowest position, travelling down a trough into the open chocolate packet, which is subsequently sealed automatically and passed along a conveyor belt. When the coupon delivery arm is in its lowest position the suspended coupon overlaps its edge and intercepts light from a small lamp directed on to a photocell. At this instant a cam mounted on a shaft of the machine, which moves in synchronism with the coupon feeding arm, closes the photocell circuit. In this position, therefore, one of two things must happen. The light is either interrupted as in normal operation, in which case the relay contacts close the circuit to an electromagnetic counter, or the light is not interrupted, in which case the supply of coupons has been exhausted or there is a mechanical defect in the feeding gear. In the latter case the no-volt release coil of the motor is actuated, the machine is shut down, and a warning in the form of a red lamp appears. A little consideration will show that the cam switch cannot, in this case, be put in the anode circuit, and must, contrary to usual practice, be included in the photocell leads, though with the exception of this modification no other change is involved.

Under the general heading of indicators we may classify one or two very simple attachments to standard factory or power-house apparatus which have merits of their own, Fig. 38 indicates a modified low-pressure water gauge. The photocell is mounted on an arm concentric with the pointer support, and can be placed in any portion of the scale. The slot which is concentric with the scale readings covers the cathode of the cell, the aperture of which is adjusted so that the pointer will close it as soon as it passes in front and record the fact on a suitable alarm. The lamp which normally illuminates the dial on all such meters suffices for the cell illuminant. The attachment has, on low pressure gauges, the advantage not possessed by any mechanical attachment —that of not affecting the accuracy of the readings by its addition. On high pressure gauges this is of less consequence, but there is always the avoidance of the uncertainty of metallic contact.

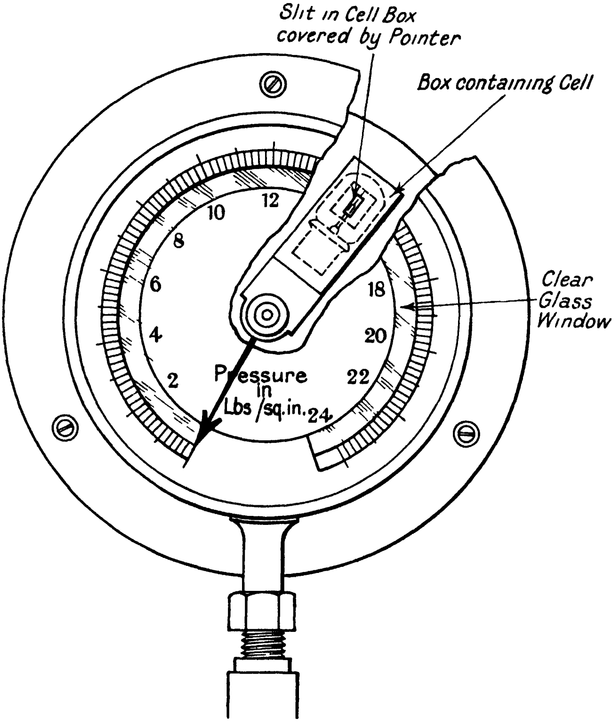


FIG 38 WATER GAUGE ALARM

Obviously, the arrangement is applicable to any type of dial meter or indicator, where change of some physical quantity is recorded by change in volume or position of some movable index. For instance, the latter may be a column of liquid in a thermometer tube, the rise of the liquid setting off the alarm, when the transmitted ray is obscured. One advantage of this is that it is easily adjustable to any portion of the scale and can be used as a thermostat to maintain equality of temperature in a heated or cooled chamber, e.g. furnace or refrigerator. The operation of the relay on a rising temperature will insert a resistance into the heater circuit and thus cause the temperature to fall slowly. As soon as the indicating liquid column passes out of the ray the resistance is cut out and the temperature rises. A slow oscillation between two extremes which can be made to approach one another very closely, thus takes place.

A possible difficulty in a case like this is the thick walled capillary tube of the thermometer through which it may be next to impossible to pass any light which will subsequently traverse the capillary before emerging. Nearly all of it will suffer internal refraction and emerge without crossing the air space. It may thus be necessary to construct a thermometer of special design to overcome this trouble. Otherwise the arrangement can be made completely self-contained.

Use has also been made of the refraction of light by the water meniscus in a boiler gauge glass to indicate high and lower water level, two photocells being used with a single light source and an indicator consisting of a bell and lamp, normally green, switching over to red. This obviates the trouble from corrosion by boiler scale, which always takes place on the usual double-float alarm.

It is obvious that such examples could be elaborated extensively, but the outline given should suffice to produce inspiration for further and more interesting practical uses of the photocell for alarms and safety devices.

It is in such applications that the simple photoelectric relay can materially assist the industrial engineer to avoid accidents and wastage of time and material.

CHAPTER V

ADVERTISING

THE air of mystery which naturally attaches itself to apparatus operated and controlled by an intangible force, makes the photocell pre-eminently suitable for advertising displays, whether these take the form of shop window shows or novelty demonstrations. Typical amongst the latter type of demonstration is that in which sound is conveyed across space through the medium of light waves. No special apparatus is required for this purpose, and it can be made to illustrate to an audience, by analogy, the production of a sound film and the subsequent reproduction of the sound from the record thus made.

Fig. 39 shows a diagrammatic arrangement of the transmitting and receiving amplifiers. A gramophone pick-up 1 feeds the grid of the first valve through the step-up transformer 2. Further amplification is secured by transformer coupling to the power valve in the anode of which is the 1:1 transformer 3. The secondary side of this transformer is connected to the negative side of the L.T. supply, and to an adjustable contact on the H.T. battery through the neon lamp 5. The adjustable contact 4 is moved until the neon glow discharge appears. If now the gramophone pick-up is put in circuit, the amplified sound currents will appear in the output side of the transformer 3, superimposed upon the normal discharge, and will be apparent to the eye as a faint flickering. If required, an ordinary wireless set may be used to modulate the neon tube from broadcasting reception, but the pick-up is preferable as the demonstration is then independent of external conditions. This discharge can be projected either by a mirror or lens system across the lecture table on to a photocell 8, feeding the three-stage amplifier shown on the right of Fig. 39. The first two stages are transformer coupled with decoupling resistances, and condensers in the anode leads and the loud speaker is fed by choke filter from the power valve in the last stage. Condensers 12 and 16 are of 2 μf capacity, and resistance 13 is of about 25,000 ohms.

The light from the neon lamp directed on to the photocell 8 produces minute electric currents which are subsequently amplified and delivered from the loud speaker as a reproduction of the original record. Interruption of the beam by any opaque object cuts off the sound from the loud speaker. Incidentally, the apparatus can be used to demonstrate the transmission of infra-red rays through certain substances which are optically opaque, the caesium cell having some response to infra-red radiation. Naturally, in such cases a certain amount of absorption occurs which will decrease the volume of sound produced.

Several precautions are necessary to obtain a satisfactory demonstration with such apparatus, and slight departures from the suggested arrangement may suffice to determine the difference between success and failure. The first two stages of the receiver should be totally screened to prevent intercoupling or the pick-up of stray disturbances. The photocell itself should be screened from daylight and artificial light, and the screens connected together and earthed. Daylight usually produces a peculiar "frying" noise, and an electric lamp on A.C. supply, a loud hum of twice the supply frequency, which will completely overpower the modulated reception. A lamp on D.C. will in any case greatly increase the background noise and generally give a predominant note due to commutator hum. Stray light from any electric supply should therefore be carefully excluded.

Each set should be operated by batteries and the two equipments not placed too close together, otherwise there will be direct capacity coupling between them, and the loud speaker will give a weak reproduction even with the photocell out of circuit. The H.T. batteries themselves are particularly prone to provide unwanted capacity coupling, and these batteries should therefore be placed as far apart as possible. Louder reception will be

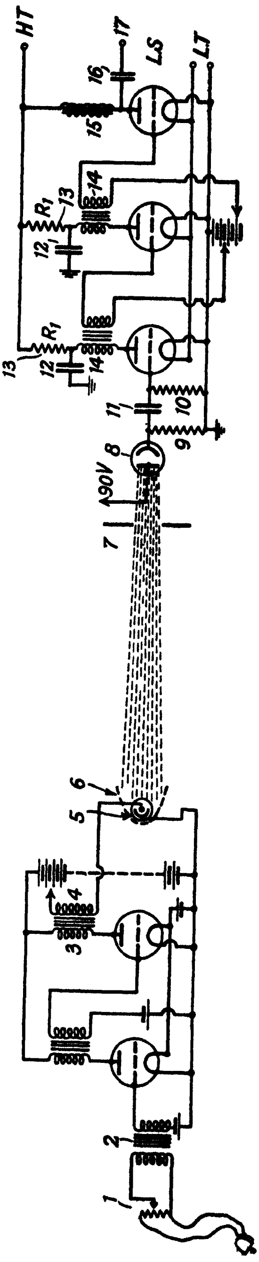


FIG 39 NEON TUBE LIGHT MODULATING CIRCUIT

obtained by increasing the value of the resistance 9, but at the expense of the quality of reproduction (cf.).

This apparatus has been described rather fully because it is extremely useful in demonstrating the fundamental operation of the photocell, talking films, and kindred apparatus with ordinary wireless amplifiers and components. Fig. 40 shows the apparatus using a radio receiver instead of a pick-up.

Signs.

The control of illuminated signs by the photocell is particularly useful in the field of advertising.

Unfortunately, much misconception exists concerning the photocell amongst potential users, and the opinion is held by some that it is a particularly fragile piece of apparatus. The mistaken idea that the small photoelectric current necessitates the use of many stages of valve amplification before it can be put to good use has mitigated against the much wider use of the photocell for automatically controlling signs by daylight and darkness. It can only be hoped that these pages will help to dispel these prejudices and demonstrate the simplicity of modern equipments.

The relay unit, already described on page 26, will suffice to operate the necessary switchgear actually controlling the sign. Some control of the light intensity at which the set switches on can be obtained either by an adjustable diaphragm over the cell aperture or by orientation of the set on the site at which it is installed. This is more fully dealt with in the section on automatic lighting control.

It is obvious that if the unit is mounted vertically it will tend to switch on earlier at night when the cell is arranged to face a northerly direction than if placed to face towards the south. These adjustments may however be determined purely by local conditions. Where the first relay is sensitive, the action both at switching on and off is quite positive, and instability of the relay is only likely to occur where an attempt has been made to separate the cell and amplifying valve by any considerable distance. In such cases a thermal relay can be included in circuit after the photocell unit; the delay in the operation of this will be sufficient to pass over the period of gradually fading daylight, where instability is likely to occur. Unfortunately, thermal relays do not usually permit of fine adjustment, and it may be difficult to secure the same time of delay in making circuit as in breaking it. The question of other methods of control of operation are dealt with in Chapter X.

The economic side of automatic sign control should not be overlooked. By its use the advertiser will ensure that the sign is on only

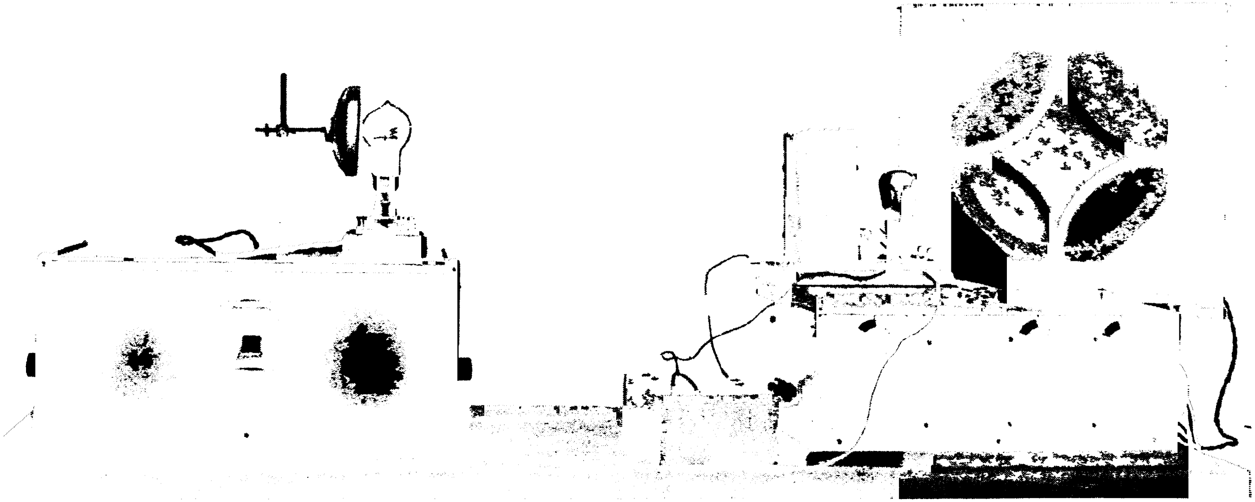


FIG 40 LIGHT MODULATION APPARATUS

when its earning capacity is a maximum and it is independent of the human element and the inflexibility of a time switch. Frequently the photocell equipment can be usefully employed together with a time switch, the latter merely performing the operation of switching the sign off at some predetermined time, say midnight, when the question of automatic control by darkness does not arise.

Economy of operating costs is most apparent in the case, for instance, of signs erected near railways where the train can be made to switch on the sign by passing across the light beam, the sign then remaining on for a predetermined period, say, 30 seconds, by means of a time delay switch, while the passengers have an opportunity to read the sign. Such control involves no danger from contacts attached to the permanent way, which would not be allowed by the railway companies. Assuming a five minute train service and the period of illumination to be 30 seconds, the current consumption is reduced to one-tenth that of continuous burning, or one-half for mechanically operated flashers, assuming the ON and OFF periods are equal. In addition, there is the novelty of the flashing sign and increase in life of the lamps. It would be possible to make the ON and OFF control by two light beams, but to make this selective in direction and to secure freedom from accidental reverse operation, that is to say, switching the sign on when it should switch off, and *vice versa*, some considerable complication would be involved, and this lack of simplicity would be the weak point of the system. The control of the main supply at sundown can be made by an independent photocell equipment or by a time switch.

Similar control can be exercised on roadside signs by the headlamps of approaching motor-cars. It is obvious that here again daylight must not interfere with the operation, and that once the sign has been switched on it must remain on long enough to be read and understood by the passing motorists. One method of securing the first requirement is to modify the standard circuit so that there is capacity coupling between the photocell anode and the grid of the valve. The arrangement then becomes sensitive only to sudden and not gradual light changes. This arrangement is not always satisfactory, as the changes in daylight are frequently very large and sudden and may be sufficient to operate the sign. In addition the approach of the headlamps of a car may constitute a gradual and not a sudden change in illumination.

A more satisfactory method is to use two photocells, one functioning by daylight and darkness and being a pre-selector to the other. A suggested arrangement is shown in Fig. 41. Here it will be seen that cell *C* which should be arranged to face towards the zenith through an aperture, will maintain the contacts *A* in the closed position only during the period of darkness, and that during daylight, although the cell which controls the sign may cause the contacts *B* to be released and closed owing to the incidence of light on the cell *D*, there will be an open circuit at *A*, and the sign will not be switched on. This arrangement avoids the use of an internally blackened tube over the aperture of the amplifier to shield the cell from extraneous light, and also to eliminate the disturbing effect of daylight.

It should be noted from Fig. 41 that contacts *A* are those which are normally open when the coil is not excited, and that contacts *B* are those which are closed when the corresponding coil is not excited.

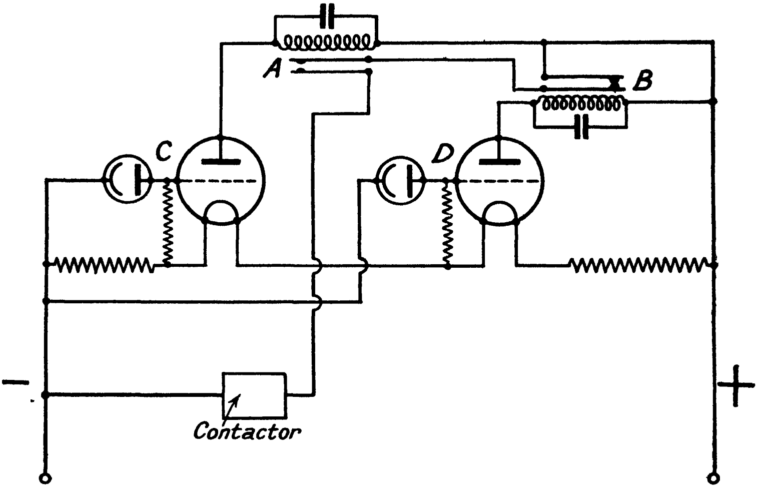


FIG. 41. AUTOMATIC ELECTRIC SIGN CONTROL

Numerous devices exist for enabling the sign to remain on for a specified period after the exciting impulse has ceased. Those involving dashpot action, or thermal control, are usually not as successful as those based on mechanical action owing to the difficulty of securing fine adjustment. Some control can be obtained by adjusting the time constant of the grid circuit (cf. page 187), but the resistances are of the order of megohms, and therefore difficult to adjust, and do not offer such flexibility of control as a mechanical movement.

A typical example of a clockwork device is shown in Fig. 42. The solenoid 1, which operates the device, is excited from the supply mains, the circuit being completed through the contacts of the relay in the photocell amplifier and through the closed contacts 7.

The solenoid 1 is tapped at an intermediate point inits winding so that it can be operated on D.C. as well as A.C. supply by a single change in connections. As soon as the coil 1 is energized, the armature 2 is raised, and arm 16 is rotated counter-clockwise about the fulcrum 17. During rotation, the boss 13 on the arm 16 bears against lever 11, causing it to rotate in the same direction and close contacts 8 and 9, through which passes the current operating the controlled sign. At the same time, the projection 4 on the arm 24 engages with the cam 5 on the lever 11, when the tension of spring 12 causes the operating coil contacts 7 to open. As soon as the display is set in motion, therefore, the exciting solenoid 1 is switched out of circuit. The time interval, therefore, starts with the exciting impulse whether the latter continues or ceases. The closure of contacts 8 and 9 takes place when the armature 2 is nearly at the end of its travel, and at this instant the pawl 18, which is pivoted to arm 16, engages the ratchet wheel 14, and sets in motion the train of gear wheels shown. The tension of the spring 20, which is adjustable by

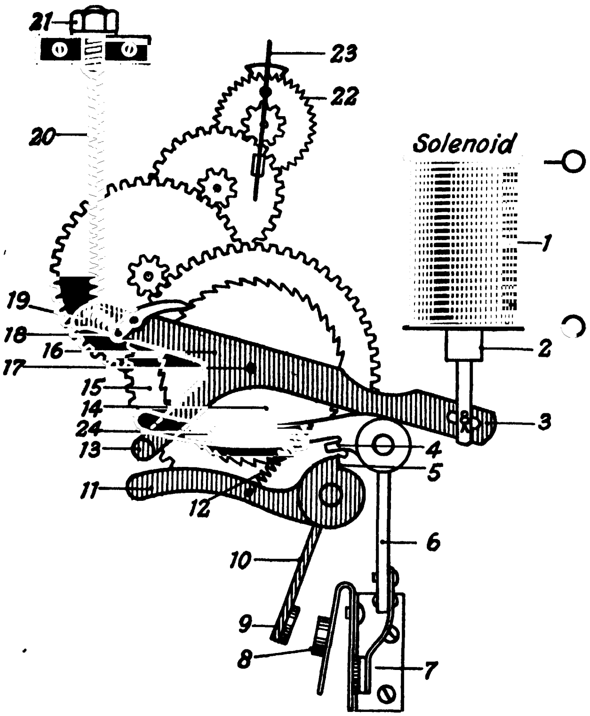


FIG. 42. CLOCKWORK TIME DELAY SWITCH

a screw 21, maintains the motion of the train of wheels which is controlled by the escapement 23, the pendulum of which is provided with movable weights to enable its period of vibration to be adjusted. When the switch runs down, the boss 13 on arm 17 releases its pressure on arm 11 and bears against lever 24, rotating the latter in a clockwise direction until a point is reached at which 4 and 5 disengage, and the tension of spring 12 opens the power circuit at

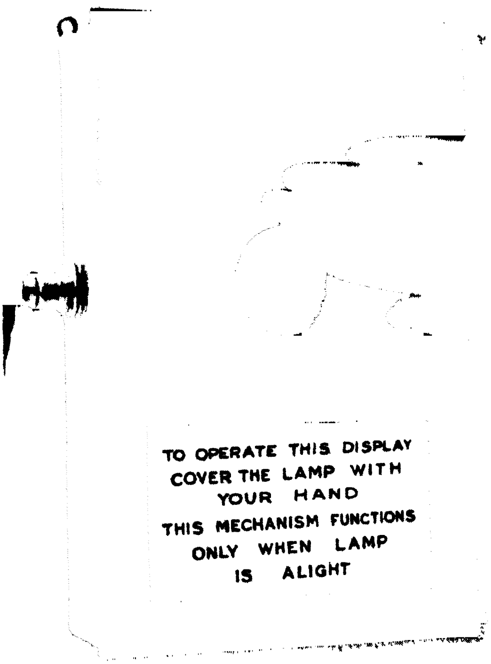


FIG 43 WINDOW SIGN CONTROL UNIT

8 and 9 smartly. When the gear has run down further the contacts at 7 are again closed, and the operating circuit through the solenoid is made ready for the next impulse. By adjusting the pendulum movement, the time between the closure and opening of the power circuit can be varied from 30 secs. to several minutes.

Recently, a good deal of attention has been paid to employing photocells for shop window displays. Other light sensitive devices have frequently been used, but it should be remembered that, as in most other cases, the photoelectric cell is equally if not better adapted for this particular application. The standard amplifier already described in Chapter II, especially for A.C. supply operation, is certainly simpler and cheaper than any other light control relay, and involves no rectifying or smoothing apparatus. Any device which gives movement of a novel character will attract a crowd and thus draw attention to the goods displayed in the window. The little unit now under consideration does this admirably, as it gives anyone the opportunity to control some display by an unseen force through the plate-glass window of the shop, and thus invariably draws rapt attention to the presentation within the window. Passers-by are generally greatly interested at their ability to set in motion a mechanical figure in a window by a movement of the hand. A simple piece of apparatus enables this to be done, and a typical attachment is shown in Fig. 43, consisting of an ornamental metal box divided by a horizontal partition into two sections. The upper portion houses the photocell, and the lower one a 25-watt lamp. The face of the box is perforated with two holes, one of which is exactly opposite the bulb portion of the lamp. The upper aperture is below the position occupied by the photocell. The back of the lower portion of the box is perforated to assist ventilation and dissipate the heat of the lamp, which also serves to illuminate the opal glass plate on which are written suitable instructions for operation. The upper section of the box is light tight with the exception of the small front aperture.

It is clear from the illustration that any reflecting surface brought up in front of the unit will reflect light coming from the lamp up on to the photocell, and the change from darkness to light on the cell cathode will operate the relay of the amplifier and cause the display to function. Sufficient light is reflected from a person's hand to work the apparatus. It is clear that, as the successful operation of the device depends upon reflected light from the lamp, the reflecting surface must not come in contact with the box itself, otherwise light leaving the lamp cannot enter the upper aperture. As the arrangement is usually placed in a shop window the thickness of the plate glass is generally sufficient to prevent this happening. Some adjustment of the upper aperture may be necessary to prevent operation by reflection from the surface of the glass, from wet pavements, and from direct sunlight. The attachment to the amplifier is made by a three-core flex, and should not exceed about 10 feet in length, otherwise the operation may be affected by cable capacities and become inoperative or unstable, as already explained.

This apparatus operates, of course, either during daylight or darkness, providing only that the lamp is alight, and may be used with or without the time delay switch previously described. In some instances the inclusion of the time delay action is less effective in impressing the spectator, as once the mechanism is set in motion the observer has no further control over it and must wait until the cycle of operations has been completed.

Novelties.

It is obvious from the description previously given that the photocell offers almost unlimited scope for ingenuity in the design of advertising novelties. It is proposed, therefore, just to give an outline here of one or two examples which may furnish some inspiration for the designer and advertising contractor.

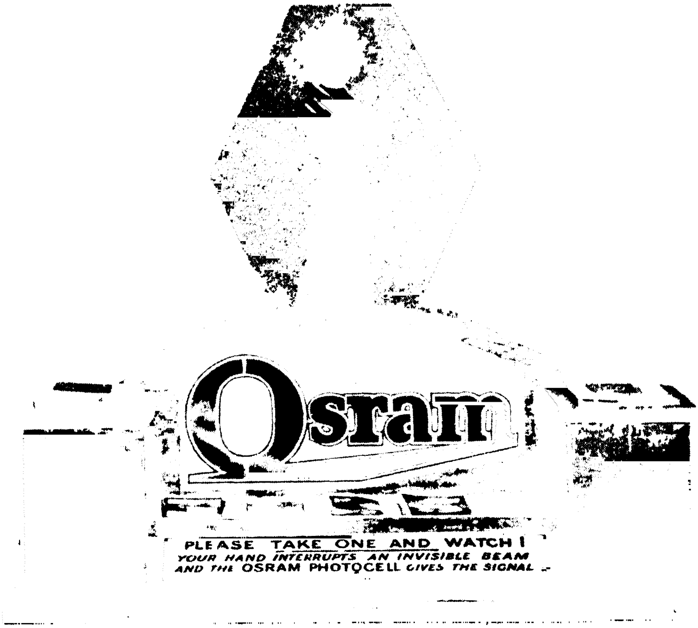

Osram
PLEASE TAKE ONE AND WATCH!
YOUR HAND INTERRUPTS AN INVISIBLE BEAM
AND THE OSRAM PHOTOCELL GIVES THE SIGNAL

FIG. 44. LEAFLET DISTRIBUTOR

Fig. 44 illustrates a demonstration used as a leaflet distributor. A row of trays which are to contain leaflets is backed by a cut-out which may be illuminated from behind or through a semi-transparent design as desired. The left-hand cubicle contains a 12-volt, 24-watt motor-car lamp, which is lighted from A.C. supply mains through a small transformer, and is installed at the focus of a double convex lens fitted to an aperture in the side of the case. A small circle of light is thus projected just above the level of the trays on to a similar aperture in the right-hand cubicle, in which is placed the photocell. The rest of the amplifier is installed behind the display. Both apertures are covered with pieces of thin ebonite after the lamp and cell have been adjusted in position, so that visible rays are cut off and only the infra-red rays cross the space above the trays. If the positions of the apertures are correctly placed it will be impossible to remove a leaflet without intercepting the beam. Whenever anyone takes a leaflet, therefore, the relay of the amplifier closes and the display is illuminated, or a bell rings, as desired.

To be most effective, the cubicles containing the lamp and photocell should be large scale models of the articles to be advertised. Wherever possible, the portion of the structure around the aperture should be black so that the ebonite window is not obvious from casual inspection. For instance, in advertising wireless valves, large model valves may be used. The caps of the valves can then be conveniently used to conceal the apertures, and the wiring can be taken out through the hollow pins in the valve base. Similarly in advertising cameras, the lens of the camera, possibly modified a little, can be used to project the invisible beam.

Another arrangement which has caused a great deal of interest, is that of a small water drinking fountain connected to an overhead cistern, the outlet valve of which is of the piston type which is opened by a mechanical lever through the action of a solenoid under the control of the photocell amplifier relay. As soon as a cup or glass tumbler is placed beneath the spout of the fountain, water immediately comes out and fills it, the flow ceasing as soon as the glass is taken away. For this demonstration, a reserve of water separate from supply mains must be provided.

Modifications of this type of demonstration are, of course, numerous, and should provide a profitable field for the advertiser. For example, instead of using a series of trays containing leaflets, as described above, the beam may be set to pass just above the cover of a closed book which the observer is invited to open. As soon as the cover is raised the invisible beam is interrupted and the interior of the book, which would be a hollow dummy open at, apparently, the first page, can be illuminated by transmitted light from below or flooded with light from above, in either case some typical slogan being thrown up in relief against a suitable background.

The control of small models by means of a hand electric torch also provides an interesting display as the equipment necessary is very simple. As in most other cases, the controlling rays can be made invisible with the aid of suitable screens. Fig. 45B is a circuit diagram, showing one method of using two photocells with corresponding valves and relays, adapted to steer a small model motor-car The body of the car houses the respective photocells which control the

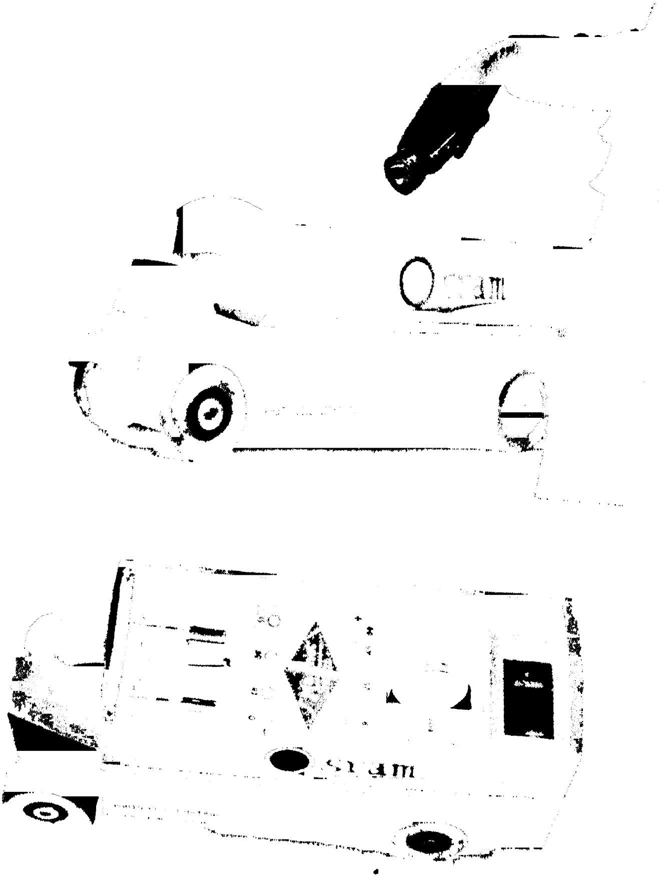


FIG 45A MODEL MOTOR-CAR WITH LIGHT CONTROL

small motor *M* operated from a battery. The same battery can also be used to supply the valve filament current, a separate H.T. battery feeding the anode of both valves. The field winding of the motor is permanently connected across the accumulator, but the armature current is reversible according to the position of the relay contacts. Normally, the housing of the cells maintains both in a state of darkness. The relays R_1R_2 are accordingly energized, contacts S_1T_1 being closed, and the armature circuit being opened. Light on cell P_1 releases contacts S_1T_1, and closes T_1M_1, driving the motor clockwise. Similarly, light on cell P_2 releases contacts S_2T_2, and closes T_2M_2, driving the motor in a counter-clockwise direction. Light on both cells again opens the armature circuit and stops the motor.

In a similar way a model automobile can be steered right or left, or bought to rest by means of a hand torch. In such a case the photocells can be concealed in the bonnet of the car, and light deflected on to them from two small right-angled prisms which may be camouflaged to represent the headlamps. Fig. 45A shows a plan view of such a model.

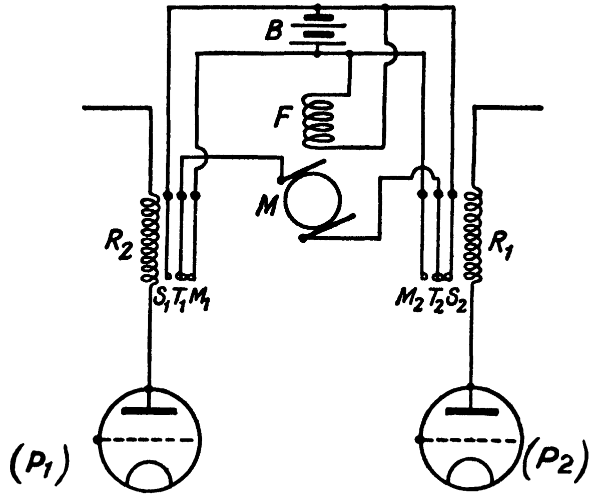


FIG. 45B. CIRCUIT DIAGRAM

In like manner a model motor-car which will obey its own traffic signals can be easily constructed. In this case only one photocell need be used inside the car, the relay in the valve circuit being arranged to keep the armature circuit closed for forward direction during the period of darkness. The appearance of the red light on the traffic control post, which will be normally focussed to be incident either directly, or after reflection, on to the photocell carried by the model car, will open the relay and switch off the motor circuit. The appearance of the green light on the control post will be equivalent to darkness on the photocell, and will be merely incidental, as the maximum sensitivity of the cell is to red light. The aperture over the cell will have been previously adjusted so that any change in colour of the light reaching the cell will be equivalent to a change in intensity.

An interesting modification of this can be made by arranging two parallel beams of light at a distance of, say, 12 ft. apart, each directed on to a photocell, the model car or locomotive carrying no equipment other than the motor, which must be reversible. This can be arranged by running the car on rails so that its direction of motion can be reversed by a switch at a distant point when it intersects the beams of light.

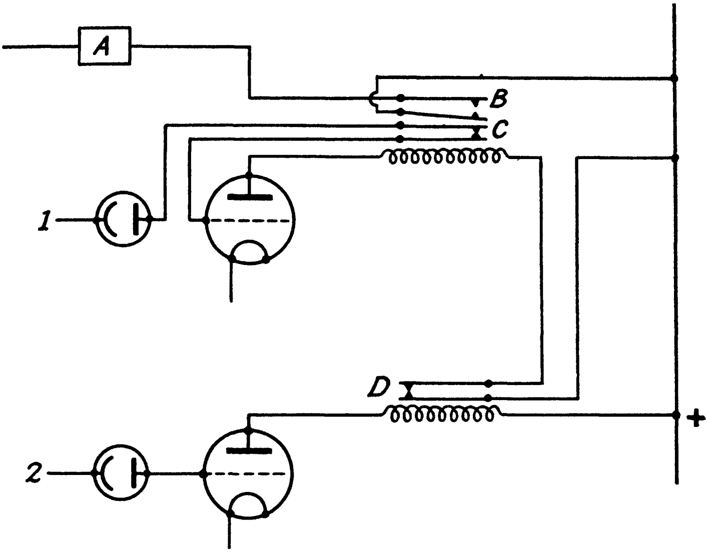


FIG. 46. CIRCUIT FOR MODEL TRAIN CONTROL

The method of interconnection of the relays is shown in Fig. 46 above. *A* represents the reversing switch controlling the direction of the car. When *A* is not excited the current supplied to the car is for forward motion. When *A* is energized this current direction is reversed, and the model runs backwards. Assume first of all that the car is between the two beams of light and moving forward. As soon as it interrupts the light beam on to cell *I*, contact *B* closes and the motion of the car is reversed by the excitation of *A*. At the same time contacts *C* open and the photocell is switched out of circuit. *A* remains energized therefore, and the car runs backwards until it intercepts the light on to cell *II*, when contacts *D* will open, at the same time breaking the circuit of relay *E* and de-energizing the switch *A*. The car will then run forward again until it intercepts the light on to cell *I*, when the sequence of reversals will be repeated.

Displays can also, of course, be set in operation by a torch held in the hand of the observer. For instance, in the case of a display for advertising wireless valves, the valve carton can have the outline of the illustration of the valve on the side of the box cut out and replaced by a piece of ground glass with the photocell fitted inside. Short leads then connect the carton to the amplifier which is behind a large cut-out figure. A time delay switch, as previously described, is used in conjunction with this model. When light from a hand-torch is directed on to the carton it starts the motor of the model, the figure goes through a series of movements, and then stops ready for the next impulse.

Numerous other examples could be cited, but sufficient has been said to give some idea of the wide scope of the photocell in the field of advertising and its utility in the development of new and interesting demonstrations.

CHAPTER VI

TALKING FILMS

THERE are at least three broad classes of recording systems for registering the sound accompaniment of talking films. The principles of operation of these systems is, by now, common knowledge, since many excellent accounts by various writers and authorities have for some time been available. On approaching the subject of talking films from our specific view-point, however, it immediately becomes apparent that the photographically recorded "sound-on-film" is the medium destined to supersede the others. It is quite certain that these others will pass into obscurity as and when the reproducing apparatus in some of the early "talkie" cinemas is brought up to date. Sound-on-film is also the most popular and convenient method of sound registration, as amongst other measures, it only requires the single standard stock film to carry the sound in perfect synchronism with its associated pictures. It is, therefore, the most convenient form of record for transporting about the country, and for operation in the projection booth of the cinema.

Other systems, such as those employing magnetic recording on iron wire, or synchronized gramophone discs, do not come within the scope of these notes, since the photocell plays no part in either their recording or reproducing apparatus. We are, therefore, forced to omit descriptions of these various systems here, together with the interesting problems of speed control, starting gear, change-overs, and the many other complexities of this new form of mechanical entertainment which might have attracted our readers' attention. We must also deny ourselves the opportunity of describing in any great detail the means of producing the photographic sound records, as it is our object to confine ourselves solely to the part played by the photocell, and to a discussion of the factors which directly influence its function in the reproduction of sound-on-film.

However, to clarify the considerations of the behaviour of the reproducing apparatus which constitute this chapter, it seems necessary to outline as a foreword, a process by which a sound-on-film record can be obtained.

The schematic arrangement of a complete talking film system is given in Fig. 47, where it will be noticed that the sounds produced in the studio are picked up by a microphone and amplified by thermionic valves in the usual way. The output of the last stage of amplification is passed through a gas discharge tube of special design. This causes a modulation of the brilliance of the glow discharge which then becomes a replica of the sound pressure wave originally impinging on the diaphragm of the microphone in the studio.

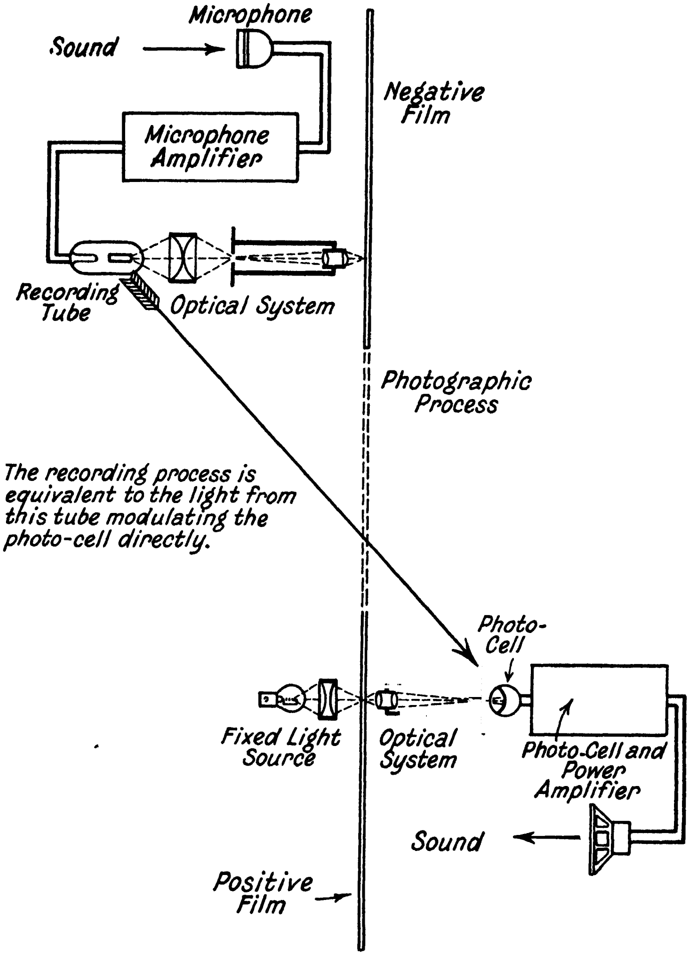


FIG. 47. SCHEMATIC DIAGRAM OF TALKING FILM

The modulated glow from this tube is projected by a suitable optical system through a very fine slit so as to form a thin line of light on the moving film. This light then fogs the negative so that

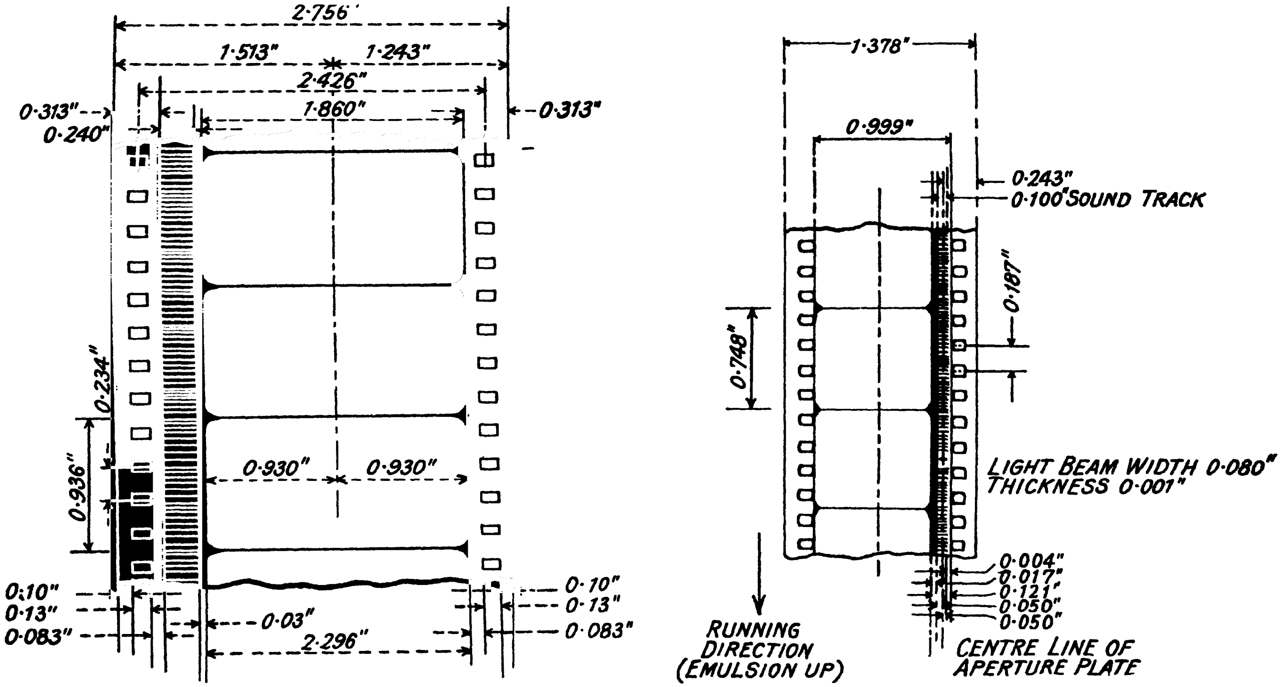


FIG. 48. DIMENSIONS OF GRANDEUR AND 35 MM. STOCK
Reduced slightly in reproduction

the sound is recorded as a continuous variation in photographic density along the length of the film.

Although only used in a few recording systems, the gas discharge tube is ideal for modulation purposes since it is free from inertia and resonances which are almost unavoidable in mechanical light valves, and frequencies up to 15,000 cycles per second have been readily recorded. The film is used in the cinema projector to modulate the light which passes from a lamp, through a simple optical system, the whole arrangement being virtually the reverse of the recording system just described.

In this reproducer is placed a photocell in the position originally occupied by the recording tube. The light on this photocell is therefore modulated by the passage of film in exactly the same way as if the cell had been illuminated by the recording tube at the time the sound film was being produced in the studio.

Other mechanisms to modulate the light are sometimes employed in the recording apparatus of most American and British studios, but the reason for these divergences in apparatus does not concern us here. These are principally due to the fact that the early recording tubes had very short lives and invariably ceased to modulate at a critical point in the dialogue. Suffice it then to assume that for our purpose, films are available on which the sound has been recorded faithfully along a small portion or track, as a modulation of the photographic density of the emulsion on this track.

The Sound Track.

When a film with sound accompaniment is being produced, the picture and sound records are, if possible, registered on separate films, the one in the camera on the set taking the scenes in the studio, and the other registering the sound in a recording room located in a distant part of the building away from all sources of noise and electrical interference. The two negatives are developed separately in the laboratory, edited, and then printed on a common positive stock with the sound track located between the pictures and the sprocket holes along one side of the film. Dimensioned drawings are given of standard cine stock, showing the space allocated to the sound track on 35 mm. standard, and 70 mm. Grandeur films. Illustrations of typical samples of these films are also given in Fig. 49, with specimens of some experimental 16 mm. "Home-talkie" sound-on-film. The sound tracks in all these films vary considerably between themselves, according to the space which can be spared in the width between the sprocket holes after allowance has been made for a reasonably-sized picture. In the 16 mm. film it is 0·05 in. wide, and in the Grandeur 0·25 in. wide. For various reasons, the sound engineer would like to appropriate a considerably larger share of the available width of the film for his purpose than can be spared by the artistic requirements of the picture. Naturally, the wider the sound track the more opportunity there is for a reasonable range in volume in the recording, and the less amplification will be required later in the cinemas to raise the minute photoelectric cell output to a power sufficient to operate the horns. So it is necessary to have as large a light variation on the cell as possible to give a cell output which then requires a lesser degree of amplification. This is explained in more detail later.

Since in the laboratory the two negatives of the picture and the sound come together at the point in the process where they are printed on a common positive, they must both receive the same time for exposure to the printing light. By recording the sound separately, the variations in photographic density required by the artistic effects in the picture, do not affect the density of the sound record. This is an important point, because it is necessary to be able to hold the mean density of the sound track at some definite value along the whole length of the film in order to secure maximum modulation with the older types of recording, and with the new "silent background" recording.

The immediate function of the photographic sound record, when in the reproducing apparatus in the cinema, is to control the amount of light falling on the photocell from a fixed source, in such a way that the instantaneous value of the light falling on the cell is proportional to the instantaneous value of the light initially falling on the unexposed film in the sound recording apparatus. In the reproducer the changes in light caused by the movement of the same sound record between the source of light and the photocell, are converted into electrical variations by means of the photoelectric properties of the cell. These variations are then amplified and passed to loud speakers located behind the screen on which the pictures are projected.

As is well known, the picture portion of the film passes through its gate in a series of small jerks, while the sound track must obviously move uniformly. Consequently, the sound track is not registered opposite the corresponding picture, but is actually 14·5 in. or 19·5 pictures ahead, and a loop of film is formed between the two gates during projection which takes up the variation of travel of the film. For although the mean velocity is the same, one is uniform motion and the other intermittent. This advance also compensates roughly for the time required for the sound waves to travel from the horns behind the screen to the seats in the centre of the average cinema, so that at that position perfect synchronism of sound and sight is obtained. In other positions in a large hall, the sound will be slightly out of synchronism by a small time interval.

As explained in our first chapter, the photoelectric cell gives a current which is proportional to the light it receives on its cathode. If then the illuminated area on the sound track is fixed, the output from the cell will be proportional to the intensity of the light coming through the film. In the "variable density" systems of recording, modulation of the light is obtained in this way by varying the density of the emulsion and using a line of light of constant width. The example of this recording (Fig. 49A) is "Movietone," developed by the Western Electric Company. If, however, the intensity of the light is fixed, and the illuminated area of the light, or its optical equivalent, on the photocell cathode is varied, a sound record of uniform photographic density but varying in width will be obtained. Such a record is said to be "variable area" (Fig. 49B), and "Photophone" is an example of this by the Radio Corporation of America. Combinations of both systems are also possible and are reported to have various advantages, the chief one being the ability to record a greater range of volume than is possible with either single method for a given width of track.

As far as the immediate operation of the photocell is concerned, however, the means by which the modulation of the light falling on the cell is obtained do not matter, as long as this modulation is a faithful replica of the original sound pressure waves.

The Photocell.

It is necessary to emphasize again that the photoelectric current is directly proportional to the light falling on the cathode of the cell, that is to say, the light transmitted through the sound track. This is, of course, the principal requirement of the conversion from light to electrical modulation. The conditions of the light modulation on the photocell in an experimental sound-head are illustrated in Fig. 50, where it will clearly be seen that the photoelectric current is a linear function of the opening of the light slit in accordance with the underlying principle. It will be noticed that the insertion of a piece of clear film in front of the slit reduces the photoelectric current by approximately 30 per cent, while the densest film reduced it by 90 per cent. So for maximum modulation between clear and densest film there is a change in photoelectric current of 60 per cent of the maximum current given when no film at all is in the sound gate. This figure will be valuable to the designer of the sound-head

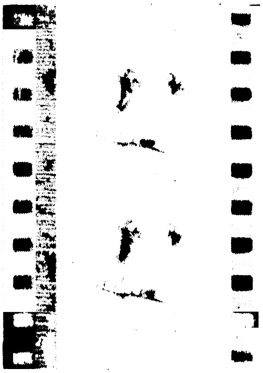


Fig 49A Variable Density Recording

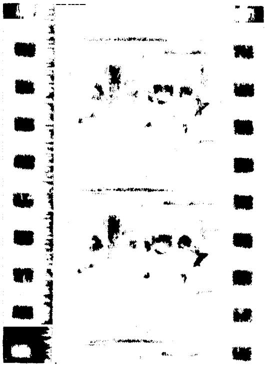


Fig 49B Variable Area Recording

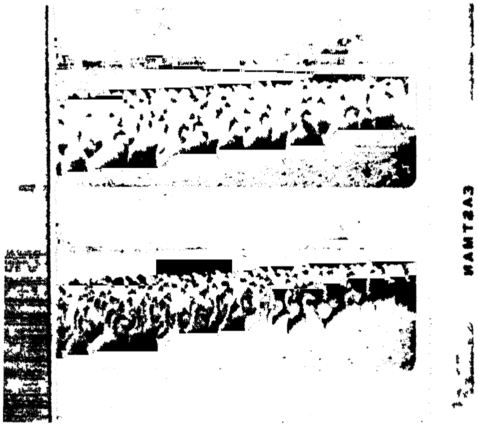


Fig 49C Variable Density Recording on Grandeur Film

Fig 49D Experimental 16 mm Variable Density Recording

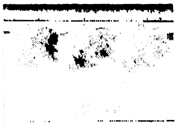


Fig 49E Experimental 16 mm Variable Area Recording

amplifier, since it gives the value of the maximum grid swing on the first valve of the amplifier. This cannot be exceeded unless the brightness of the light source, or the anode voltage on the cell is increased in some way. For, from this curve it is seen that with a change from minimum light to maximum light there is a change in photoelectric current of 3·5 microamperes, which corresponds to an r.m.s. current of 1·25 microamperes approximately. This curve also demonstrates that there can be no form of amplitude distortion due to the photoelectric cell itself, provided that all the light modulation falls on the cathode of the cell. It is essential that this point is observed, but it is important at the same time, that the light received on the cathode is not concentrated on a very small spot. For it is found that with a slight variation in sensitivity over the cathode surface, amplitude distortion may become apparent with variable area recording under certain circumstances. Also, due to this slight variation in sensitivity of the cathode, a form of microphonic noise can be produced if the cell is free to move and can vibrate relatively to the beam of light. This noise gives the impression of a ringing note as a background to the sound, or a tremolo on sustained notes,[1] depending on what part of the mechanism of the projector is the cause of the vibration. There is some variation in sensitivity between different parts of the same cathode, but for the small

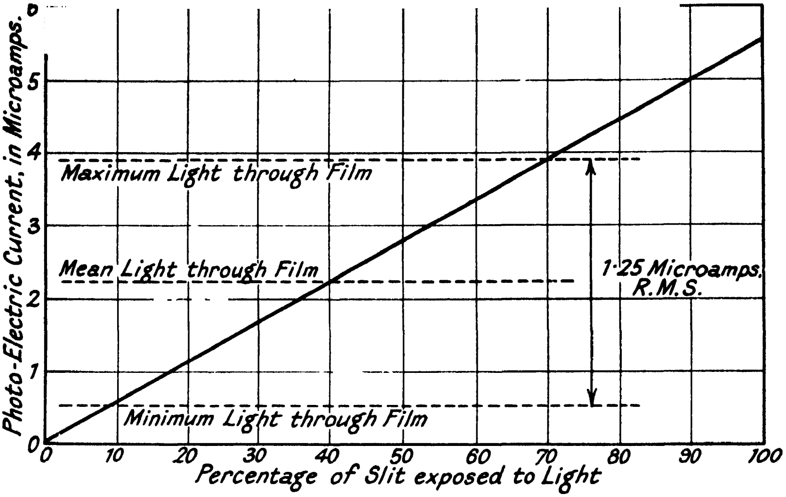


FIG. 50. PROPORTIONALITY OF LIGHT MODULATION

areas of illumination which usually occur in a sound head, the sensitivity is reasonably constant. Very little microphonic effect, or ringing noise, can be obtained from the vibration of the electrodes inside the cell itself, provided that the illuminated area of the cathode does not vary by passing off the edge of the cathode during the vibration period. However, as a precaution, it has become customary to mount the cells in antiphonic sockets or holders to reduce this trouble. It is hardly necessary to point out that loose wire connections to the cell terminals can produce far more distressing noises in the apparatus, and that in most projectors the effects mentioned above are completely overwhelmed by the distortions due to the unsteady running of the driving gear and the background noises due to the grain of the emulsion. Only in elaborate laboratory equipment in which the drive of the film is absolutely constant, can these technical defects be produced sufficiently free from mechanical troubles to be noticeable by ear unless the most obvious precautions are violated.

---

[1] Colloquially known as "wow-wow" in the cinema industry.

Background Noise.

These troubles just described add small spurious noises to the reproduction, and as there are several other things contributing to a far greater extent to the same effect, it would be advantageous to consider them collectively.

Most of the background noise heard in the loudspeakers of a reproducer of sound-on-film is due to grain noise on the sound record, produced by changes in the average number of grains in the emulsion passing the line of light, scratches and dirt on the film, and similar causes. In fact, this background noise is the one serious disadvantage of sound-on-film in comparison with other systems of sound recording, for the noise so produced has components throughout the audio-frequency range, and is therefore very difficult to eliminate. With wax recording, the background noise lies just above the frequency range required for reasonably good reproduction. A very simple electrical circuit can be arranged to filter this undesirable noise, and usually, most electrical gramophone pick-ups can be designed to cut off at a frequency just below the background noise.

To give an impression of the relative dimensions of size of the grain, the wave forms of the sound record, and the width of the line of light, we have prepared two photomicrographs of sections of the films, shown in Figs. 51A and 51B. Here, under a magnification of 200 times, the emulsion can be compared with the width of the line of light. As this emulsion passes through the line of light before the photocell, the noise due to the granular structure becomes audible. Naturally, the longer the area illuminated in comparison with the grain size, the less does the noise interfere with the required sound output

The introduction of the biased valve method of recording has resulted in a reduction of the grain noise to $\frac{1}{10}$ (10 decibels[1]). This is accomplished by keeping the amount of light admitted to the photocell always at a minimum value. Thus the grain noise is reduced proportionally as is the amount of light admitted to the cell.

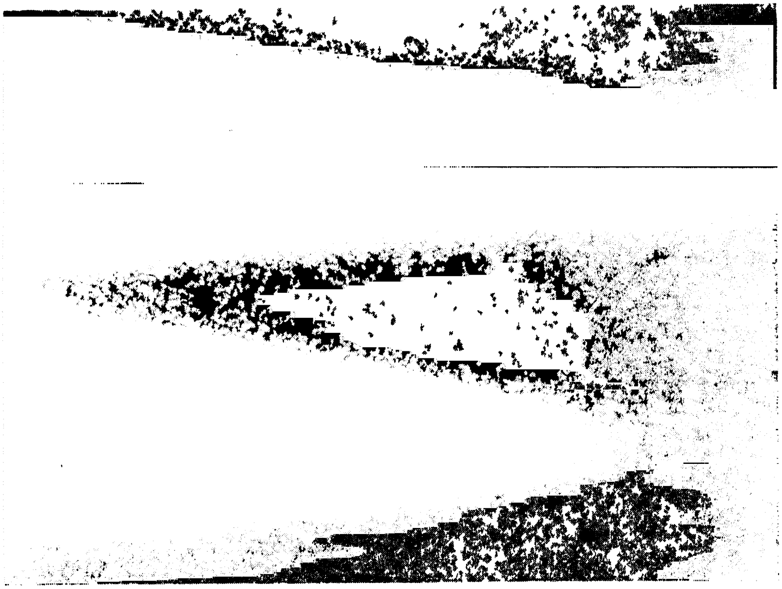


FIG 51A ·PHOTOMICROGRAPH OF PORTION OF SOUND TRACK IN FIGURE 49B SHOWING GRAIN SIZE IN RELATION TO LINE OF LIGHT (× 200)

If we consider only the variable area method of recording (see Fig. 49B) in describing this improvement, we note that with no modulation there is half the sound track clear film and half black. Under the new method of recording, the mean or datum line of the modulation is carried close to one edge of the sound track. With this condition then, when there is no noise recorded, there is very little light on the photocell through the film. As the modulation is applied, the mean line is moved towards the central position by a mechanism controlled by rectification of a small portion of the current passing to the light valve in the recorder. This can be better understood by an inspection of the diagrammatic representation in Fig. 52. It must be realized that this is a very crude illustration of the actual process, for in practice the time base would be considerably extended, and the effect of the moving datum line would not be so strikingly emphasized.

---

[1] See p 106 for definition of the decibel unit.

In present-day 35 mm. film, the sound volume range is about 25 decibels above the ground noise level with 0·001 in. slit 0·1 in. wide, and a film speed of 90 ft. per minute. With the new Grandeur 70 mm. film with a sound track 0·25 in. wide, and a film speed of 120 ft. per minute, a 70 decibel volume variation above ground noise is obtained with 0·001 in. slit. This is a greater volume range than is required for the recording of a full symphony orchestra, and it is now possible to record organ and orchestral works with true quality and modulation on Grandeur film without a volume control and without the background noise detracting from the performance.

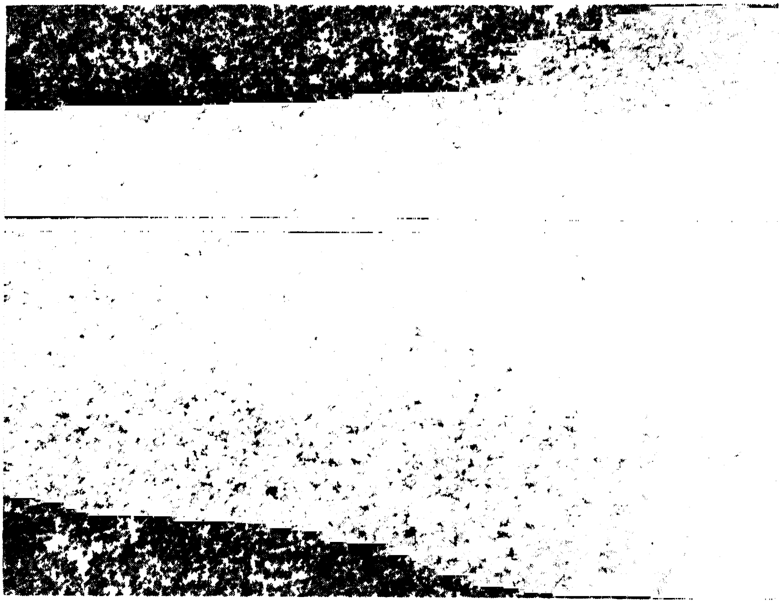


FIG 51B PHOTOMICROGRAPH OF PORTION OF SOUND TRACK IN FIGURE 49A SHOWING GRAIN SIZE IN RELATION TO LINE OF LIGHT (× 200)

With the present 0·1 in. sound track, this volume range has to be obtained by manual manipulation of a potentiometer on one of the amplifiers. The operator is provided with a cue sheet for each film, and he alters the setting of this potentiometer in accordance with instructions set out on this sheet. The potentiometer normally has a range of 45 decibels, so that large changes in volume can be obtained at the appropriate times in the performance if the operator has the opportunity to watch both the film and the cue sheet.

Although some part of the noise of the reproducer may be due to the photocell and the valves in the sound head amplifier, the grain noise on standard films is at least 10 times (10 decibels) more than these. An analysis of the various noises has been carried out very fully by H. G. Tasker, and his results are reproduced here owing to their particular interest. The relation of total background noise, and the Schrot effect to the full sound recording level, is shown at various frequencies in Fig. 53.

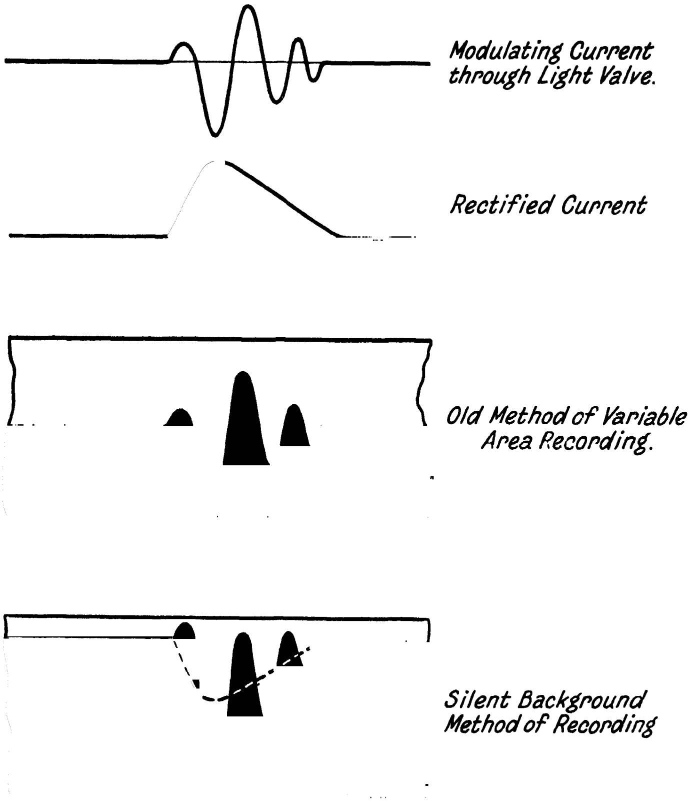

Modulating Current through Light Valve.
Rectified Current
Old Method of Variable Area Recording.
Silent Background Method of Recording

FIG. 52. SILENT BACKGROUND RECORDING

Considerable "frying" noise can be introduced by the photoelectric cell if at any time it has been damaged by the passage of the glow discharge. This discharge, unless minimized by a very high protecting resistance, leaves the cell with an internal insulation leak between the electrodes and, consequently, a dark current which produces instability in the cell.

The Schrot effect, which is a similar noise, is due to slight irregularities in the emission from the cathode. It is the effect met with in thermionic valves, but is only apparent in high-gain amplifiers. In a talking film amplifier, the effect is usually 50 decibels below the average sound output, and is therefore, negligible. Theoretically, the Schrot effect is inversely proportional to the square root of the illumination, so that the noise produced is independent of any variation of the illuminated area of the cathode if the total amount of light falling on the cell is constant.

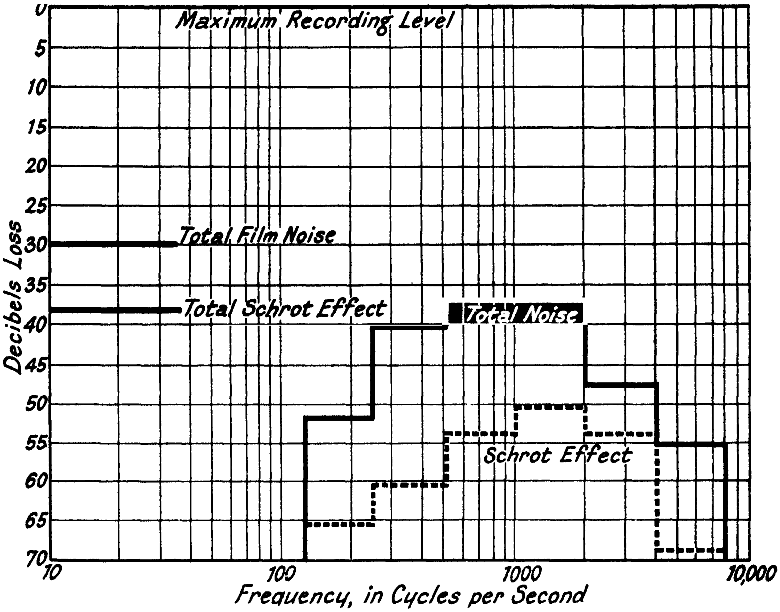


FIG. 53. NOISE ANALYSIS OF SOUND ON FILM

Optical Systems.

We have mentioned that the sound-on-film modulates the light falling on the photocell from a fixed source. This source is usually a metal filament projection lamp fitted in an optical system which produces a thin line of light across the direction of motion of the sound track. This line of light is usually about 0·001 in. wide, but recently it has been found possible to close up the width to 0·0003 in., and thus extend the frequency range of the amplifiers with correspondingly improved intelligibility.[1] It is, of course, essential that the illumination across the line of light be uniform, otherwise strange amplitude distortions will be introduced with variable area recording. To ensure this, it is necessary to avoid producing a reduced image of the filament for the line of light, unless special ribbon filament lamps are used, because the convolutions of the spiral filament will cause patchy illumination. This trouble is readily emphasized by reference to Fig. 54, where a photograph taken on an experimental sound head shows that not only is the illumination uneven, due to the sharp image of the filament being formed on the film, but the axis of the filament is not parallel to the line of the slit, so that the end portion of the slit is only partially illuminated. This latter fault will introduce amplitude distortion to a very serious extent. An easy method of checking this distribution of illumination across the slit is by arranging a metal slide which can be moved across the slit in steps. At each position of the slide the photoelectric current from the cell is measured, and the uniformity of the lighting can be checked.

FIG. 54. BAD ILLUMINATION OF OPTICAL SLIT

The Vintern Sound Head.

This sound head, which is noted for the excellence of the mechanical design and precision of the manufacture, embodies a very simple optical system. The film slides past a curved steel sound gate without any pressure pads or rollers, the film keeping against the curved surface by virtue of the fact that the gate is placed slightly forward of the line joining the two sprockets, and the tension of the drive from the lower sprocket therefore holds it in position when running smoothly. Good mechanical design of the shock absorbers in the driving gear ensures that this tension is uniform so that the film speed is constant.

---

[1] Influence of slit width. *Funk Heft* 36, page 595, 1930.

The light from a standard 60-watt exciter lamp is condensed by a lens and illuminates a small area of the sound track where the latter passes over the sound gate, and the light then passes through a hole cut in the sound gate. As a rotating lamp-holder with two lamps with a preset focussing arrangement is used, no difficulty in changing over is experienced.

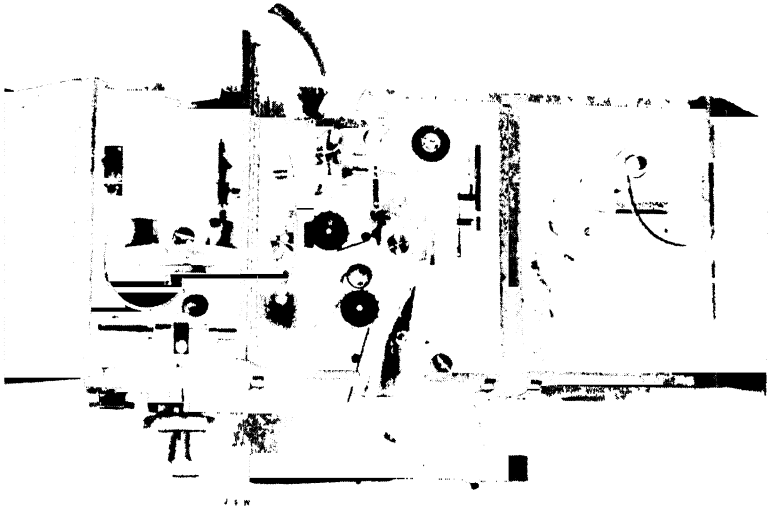


FIG. 55. THE VINTERN SOUND HEAD

(W Vintern & Sons)

A microscope objective with a magnification of eight times then forms an image of the illuminated sound track on to an adjustable metal slit mounted on the outside of the cell compartment. The light which passes through this slit falls on the cathode of the photocell and modulates the output as already explained. This arrangement has the advantage that the slit is eight times the width of its optical equivalent on the film, and in consequence dirt and grease on the film cannot reduce volume by closing up the gap, as happens with the narrow light slits used on some systems.

The designers do not deal with the amplifiers for the sound heads, so plenty of space is left for any form of coupling to the cell. Fig. 55 shows the three metal compartments containing the lamp-changer, the drive and sound gate, and the photocell.

The Mihaly Sound Head.

This sound head is of unique and simple design, and is intended for attachment to " silent head " projectors, enabling sound-on-film records to be reproduced. The film, on leaving the picture gate, passes over a hollow sprocket with a steady drive and then into the lower spool box. The light from a 60-watt exciter lamp is condensed on to the sound track, and passes through the film and a prism down the hollow shaft on which the sprocket runs. Another prism at the end of this shaft turns the light outwards on to the photocell unit where an image of the sound track is formed on an adjustable slit in front of the cell. The photocell is mounted on the wall of the projection booth away from the projector so that mechanical vibration from the intermittent gear does not create microphonic disturbances in the cell coupling and first valve amplifiers.

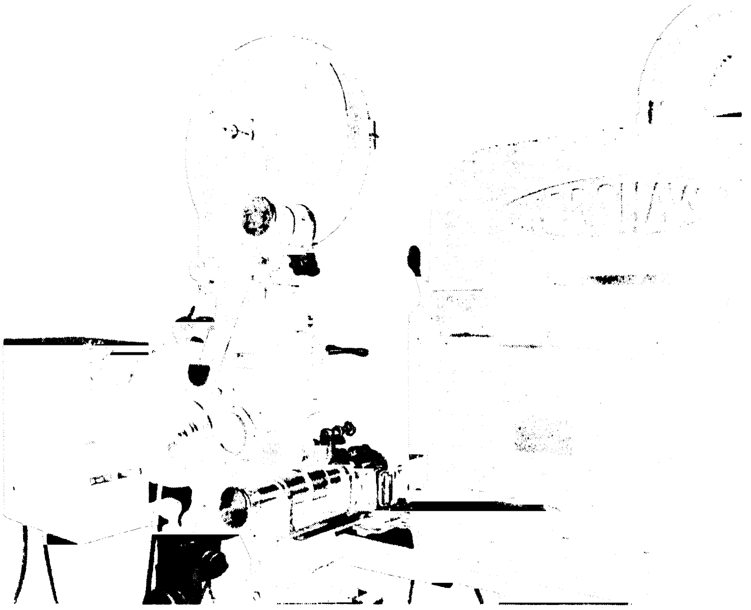


Fig. 56A. The Mihaly Sound Head on Projector

Fig. 56A shows the complete equipment with the two exciter lamps, one of which is a spare, the hollow shaft extending outside the apparatus, and the cell and amplifier unit. In Fig. 56B a sectional view of the optical system is given, showing the two prisms and the lens which forms an image of the sound track on the distant photocell unit.

Light Sources.

The lamp used as a light source is generally a gas-filled automobile lamp with a straight spiral filament, or a development of this with special bulbs and mountings. This type of lamp has a very high luminous efficiency and is manufactured to extraordinarily close tolerances for the position and dimensions of the filament, enabling the lamps to replace each other in their holders with only a very small range of focus. This is a tremendous asset to the operator in the cinema, because in some apparatus where blue sensitive potassium cells are used, the filament of the lamp has to be considerably over-run to get a good response in that part of the spectrum to which the cell is most sensitive, and the lives of the lamps are thereby reduced. Under these conditions the lamps are very apt to fail at inconvenient moments, and the change-over to a new lamp and the refocus must be made quickly to avoid a break in the continuity of the sound in the programme. Many elaborate and ingenious mechanical devices have been invented to effect this change automatically, but prevention is always better than cure, so with the introduction of red sensitive caesium cells this difficulty and its attendant complications disappear, for now ample radiation can be obtained with the same lamps running at normal voltage, and the guaranteed lives are therefore possible. It is a point worth noting that with this type of gas-filled lamp, 1 per cent over-voltage reduces the life of the filament 6 per cent, as is shown in Fig. 57, so that ability to obtain sufficient output when the lamp is operated

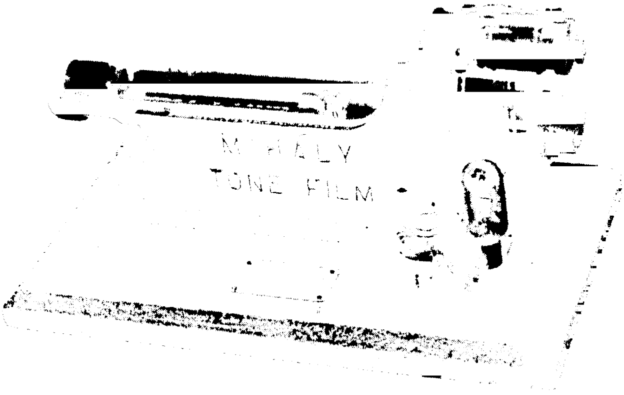


FIG. 56B THE MIHALY SOUND HEAD (CLOSE VIEW)

at the temperature at which it has been designed to burn, is a great advantage.

This is a theoretical curve which is, however, consistent with life test results on a large number of lamps within the limits of 10 per cent of nominal volts. Inconsistent results occur with larger overloads and, therefore, outside these limits the curve can only be considered approximate. It illustrates, however, the difficulty encountered with short lives of lamps when used with potassium cells. This same limitation must be borne in mind when examining Fig. 50. There is also no risk of trouble due to the filament sagging out of the line of focus of the objective lens, which often happens with over-run lamps to the detriment of the reproduction of the sound.

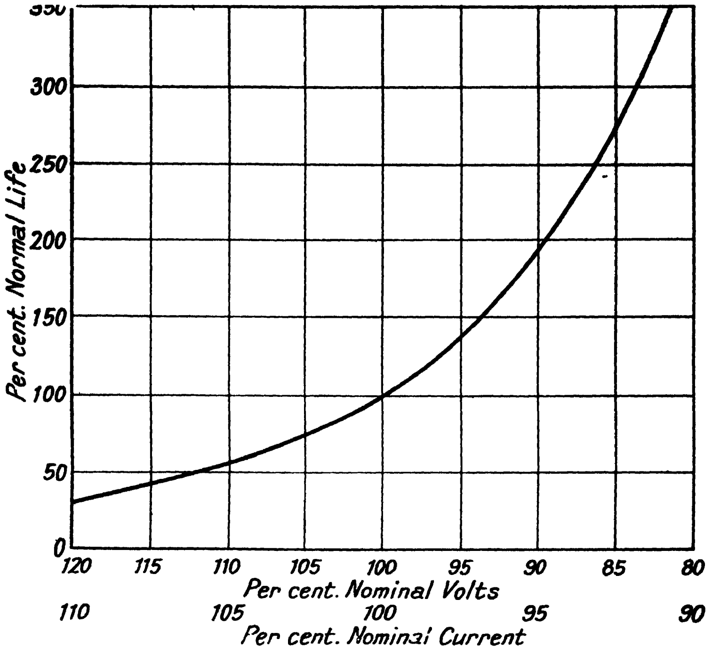


FIG. 57. GAS-FILLED LAMP CHARACTERISTIC

A further advantage obtained by the use of caesium cells is that extremely satisfactory results can be obtained when only the infra-red radiation from the lamp is used. This radiation, which is, of course, invisible, can be separated from the visible radiation of the lamp by the insertion of a Wratten filter (No. 89*a*), at some part of the optical system, preferably near the photocell window, where it will also serve to protect the cell from sudden bright lights.

With this arrangement, the sound reproduction is unaffected by the changes in colour of the emulsion which are occasionally required for artistic or emotional effects in the picture part of the film. With cells having a maximum colour sensitivity in the visible range of the spectrum, colouring of sound-on-film presented difficulties owing to the noises and changes in loudness which were heard when the colour of the dye ran on to the sound track. A special series of tints was developed by the Kodak Co., which all produced the same attenuation with potassium cells. These enabled emotional tinting to be possible without changes in loudness. However, these tints was very weak and unsuitable for natural colour films. Later, it was found that with the caesium cells and filter quite satisfactory results could be obtained with most conditions of colouring of the films. Usually, however, the natural colour is obtained by dividing the emulsion of the film into patterns. These patterns are either regular or irregular and are dyed, the three complementary colours being set into a matrix of black. If this formation then passes the light to the photocell, a very bad background noise is obtained. The colouring process, therefore, usually has either sound-on-disc recording or else the emulsion is carefully planed off the film base where the sound track is to be located and a separate emulsion applied for recording the sound.

This modification of the light system with infra-red filters is, however, covered by British Patent 342115, for a further and more interesting reason. Previously, the exciter lamps have always been lighted from storage batteries or by metal rectifiers of large current capacity from the A.C. mains, because the intensity of the light source must be very steady, and when heated by alternating current, the filament temperature and, hence, the intensity of the light follows the alternating current, and a hum of double the mains frequency modulates the output, making reproduction quite impossible. It has been found that radiations at the red end of the spectrum do not follow the temperature variations to the same extent as at the blue, and so with the infra-red filter this modulation at double mains frequency is practically eliminated. Definition is improved in the optical system, and a cheap non-colour corrected lens may be used, at the same time there is less dispersion in the film which usually causes loss at high frequencies. A great saving in apparatus and elaborate changers has therefore been brought about by the introduction of these new caesium silver cells, used in conjunction with a simple infra-red filter.

Frequency Response.

It is now necessary to consider the response of photocells to varying illuminations when the frequency of the illumination covers the band, designated the audio frequency band, that is, from 50 to 6,000 cycles per second for this is the range of frequencies which is likely to be found on records made by the sound-on-film systems. It is possible to record higher frequencies, and to reproduce them again on special apparatus, but the majority of designers agree that 50 to 6,000 cycles per second is the range which gives good intelligent reproduction on apparatus of robust and reliable manufacture. It should be clear that the upper frequency limit is set by the size of slit and the film speed. For instance, at a film speed of 90 ft. per minute, or 18 in. per second across a slit of ·0003 in., a frequency of 6,000 is the upper limit. Anything higher than this, even if recorded on the film, cannot be reproduced without either decreasing the width of slit or increasing the speed of the film.

The easiest way of producing such an illumination for testing sound-head amplifiers and for purposes of comparison between cells, is to project a beam of light on to the photocell through a thin revolving disc which has a series of circular holes through which the beam can pass. If these holes are circular and spaced two diameters apart, running past a fixed rectangular hole one diameter wide, the light variation on the cell will be approximately sinusoidal. By controlling the speed of revolutions of the disc, the frequency can be varied. Such an arrangement is shown diagrammatically in Fig. 58.

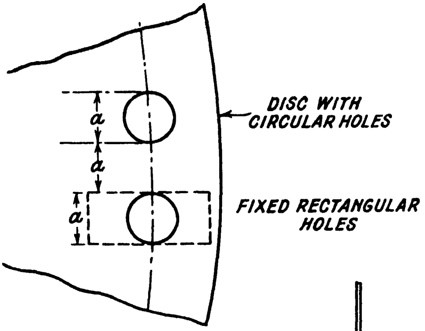
The disc in this apparatus has 160 holes equally spaced around a pitch circle of about 18 in. diameter and gives a light interruption of 8,000 cycles per second when the motor is running at 3,000 r.p.m.

It will be noticed that all the measuring equipment is enclosed in a heavy galvanized iron tank which protects it from interference from external electrical apparatus, and other causes which might add fictitious value to the readings. The disc is driven by a half horse-power synchronous motor which is run up to full speed before a frequency characteristic is taken. When ready, the current is switched off, the motor slows down, readings taken on a stroboscopic disc on its shaft, indicating that the desired frequencies are being produced. In this way interference due to sparking or induction from the motor is avoided. Attention is called to the section in Campbell and Ritchie's book,[1] page 137, dealing with sources of interference in this class of measurement work. It is almost impossible to take enough precautions to ensure that the measurements recorded are those actually required.

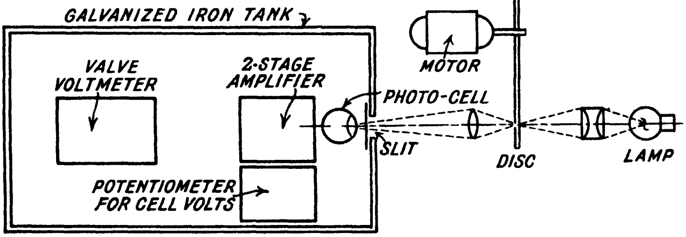
---

[1] *Photoelectric Cells* (Pitman).

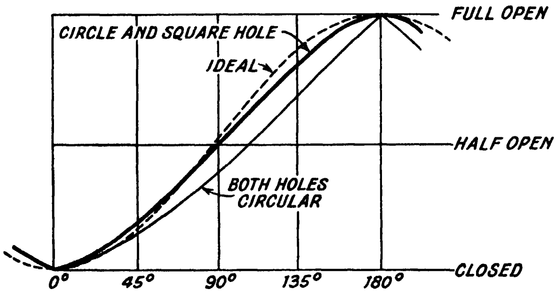
A small portable testing equipment has also been used with the



DETAILS OF HOLES.



LAY-OUT OF AMPLIFIER



WAVE-FORM WITH THIS ARRANGEMENT

FIG. 58. APPARATUS FOR TESTING FREQUENCY CHARACTERISTICS

experimental sound heads already described, in which a small disc of celluloid about 6 in. in diameter is rotated in the actual sound gate of the projector. This has a sinusoidal track similar to variable area recording produced round its periphery by photographic reduction from a large drawing. This proved quite effective for rough calibration, but of course does not approach the laboratory equipment for reliable work.

The Decibel Notation.

Most response curves of an acoustic and electrical system are usually plotted as, say, sound pressure, output voltage, amplification, etc., to a logarithmic base of frequency, and as these results always make the performance of the apparatus appear very much worse than an aural test, it is necessary to depict the results in a way which will give a better graphical impression of quality.

Power Ratio	Decibels
100,000 : 1	Gain 50
10,000 : 1	,, 40
1,000 : 1	,, 30
100 : 1	,, 20
10 : 1	,, 10
5 : 1	,, 7 (approx.)
2 : 1	,, 3 (approx.)
1 : 1	,, 0
1 : 10	Loss 10
1 : 100	,, 20

FIG. 59. TABLE OF DECIBEL RATIOS

This is partly possible by the decibel notation of telephone engineering, for having a logarithmic basis, it approximates to the apparent impressions experienced by the ear. With this notation, the change in noise, which can just be detected by a well-trained ear, is 1·5 decibels, but 3 decibel steps are only just noticeable to the ordinary ear. It is our practice, then, to plot response curves with 3 decibel levels relative to the condition at 1000 cycles per second (mean speech frequency) against a logarithmic frequency base, and in the following discussion we shall use this notation for all diagrams which bear a relation to the audible output from the reproducing apparatus. It must be noted that since the decibel is a measure of power ratio, the actual value of the standard at 1,000 cycles per second must always be stated for any particular reference. Hence two powers P_1 and P_0 are said to differ by $10 \log_{10}\frac{P_1}{P_0} = N$ decibels, and so if P_0 is regarded as a reference level, and P_1 is greater than P_0, the value of the decibel ratio, N, say, will be positive, and P_1 is said to show a gain of N decibels over P_0. When dealing with voltages and currents, it is necessary to consider them in association with a constant resistance. Thus as $P = I^2R$ or $\frac{V^2}{R}$, two currents differ by $10 \log_{10} \frac{I_1^2R}{I_0^2R}$, or $20 \log \frac{I_1}{I_0}$ decibels. A positive decibel notation indicates a gain over the standard level, and a negative decibel an attenuation or loss.

For the ideal talking film equipment, in which the output sounds from the loud speaker are to be a replica of the sounds originally made before the microphone in the studio, it is necessary that all such sounds are picked up, recorded, amplified, and reproduced to the same extent. This means that no particular frequencies, or bands of frequencies, are either favoured or attenuated by an amount which is noticeable to the human ear. It is important then to consider the question of the frequency response of the photoelectric cells.

We have already shown that errors in the design of the optical systems and the increase in width of the light slit beyond the correct value, tend to reduce the response of the high frequencies in relation to the rest of the modulation of the light.

Having corrected these faults by careful study, the designer is now faced with the possibility of the light sensitive device itself introducing distortions which might be of even greater magnitude than those he has been considering. Here, of course, he is entirely in the hands of the cell manufacturers for information, unless he is prepared to set up elaborate apparatus for checking the frequencies himself. Fortunately, a great deal is known about alkali metal photoelectric cells as regards the frequency response, and curves have been published by many authorities showing the relation of the output of the cells to the frequency of the light changes incident thereon. Any distortion of this nature, attributable to photocells, is of reasonable value, and can be equalized in the amplifier or some other part of the system, and so the modulation is corrected before being passed to the loud speaker. Thus, it will be seen that in this application the time lag of both vacuum and gas-filled cells must be studied very closely. We have already emphasized that as far as is known, the emission of electrons from the cathode of the cell takes place instantly. No one has been able to measure a time lag between the incidence, or change in the illumination and the emission of the electrons, and in a vacuum cell where this is the only effect taking place, the current varies in exact proportion to the fluctuating light at any instant. A gas-filled photocell with low anode voltage exhibits the same characteristics, but as soon as magnification by ionization is utilized, by increasing the anode voltage, there is a frequency distortion. The process of ionization, as explained in the first chapter, takes a definite time to reach its full effect, so although the emission of the electrons is instantaneous with the incidence of the light, the anode current does not reach its maximum value immediately. This means, that with rapid changes in illumination, there is a definite time lag in the photoelectric currents. When the cell is subjected to a high frequency light change, this defect shows up as an attenuation and a phase angle, both of which should be corrected. At the same time the interelectrode capacity between the cathode and anode, which cannot be reduced below its present value without sacrifice of efficiency of the cell, tends to attenuate the high frequencies, and, hence, augment the amount of correction necessary. This effect is illustrated in Fig. 60A, for which a rather bad condition has been purposely chosen. The cell used to obtain these results, was the type in which the cathode was deposited on the inside of the glass bulb so that the capacity between the cathode and the protecting metal case was higher than in the modern cells. It will be seen that as the anode potential is increased, the slope of the

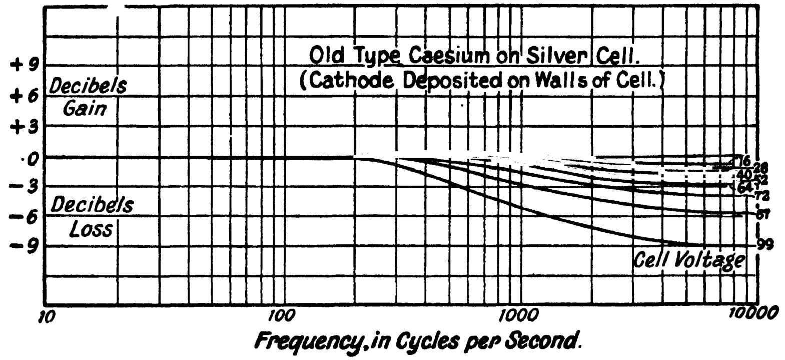


FIG. 60A. FREQUENCY CHARACTERISTICS (OLD CELL)

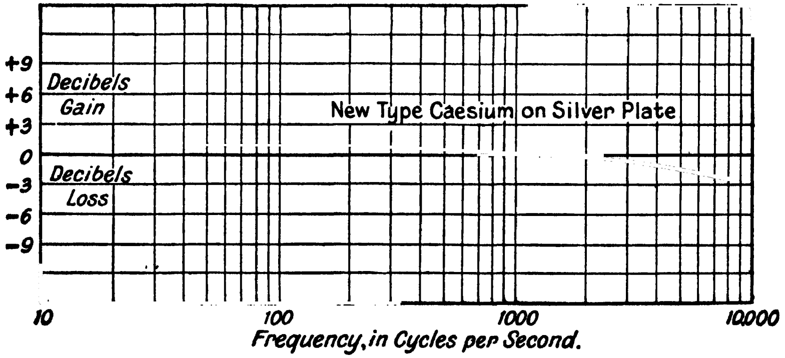


FIG. 60B. FREQUENCY CHARACTERISTICS (MODERN CELL)

frequency characteristic increases, but never to an extent which cannot be equalized in a simple manner in the amplifier.

A similar characteristic (Fig. 60B) is given for the new caesium-on-silver photocells which have been specially developed for use in talking film sound-heads These cells are intended to be used at a definite anode voltage, which is marked by the manufacturer on each cell. This is the voltage at which full advantage is taken of amplification due to gas-filling but at which the frequency response is not impaired. In this way the frequency characteristic can be guaranteed and relied upon by the user.

Cell Coupling.

In picture telegraphy, talking films, television and kindred applications where the rapidly alternating outputs from photoelectric cells have to be amplified from microwatts to sometimes several watts without appreciable attenuation over a stipulated frequency band, one difficulty which immediately arrests our attention lies in the coupling between the photocell and the first valve of the amplifier.

We have shown that over the frequency range considered necessary for intelligent reproduction with a talking film apparatus, the latest design of photocell causes only a slight frequency distortion. We must realize, however, that considerable distortion may be introduced in the connections between the photocell circuit and the input to the amplifier.

Let us examine in Fig. 61(*a*), the typical coupling arrangement, in which the potential drop E_0, due to the passage of the photoelectric current i_0 through the resistance R, is applied to the grid of the first valve of an amplifier. These connections, including the cell itself, will have a capacity C, which forms a shunt on R, and the effect of this shunt increases as the frequency of i_0 is increased. The sensitivity of the circuit will, of course, be measured by the ratio $\frac{E_0}{i_0}$ since we always desire E_0 to be as high as possible for a given current in order to get a large grid swing and, in consequence, lower the gain of the amplifier.

With the simple shunt capacity circuit shown, the sensitivity can be expressed as

$$\frac{E_0}{i_0} = \frac{R}{\sqrt{1 + 4\pi^2 n^2 C^2 R^2}}$$

where n is the frequency of the alternating circuit produced by the fluctuating light on the cells.

It is clear, then, that for maximum sensitivity R requires to be large, but unfortunately the term $(2\pi nCR)$ also becomes at the same time large compared with 1, and so the sensitivity $\frac{E_0}{i_0}$ is reduced as the value of the frequency rises, which is the effect we least require. If C, which includes the interelectrode capacity of the cell and the input impedance of the valve, is made small, then it is possible to arrange that this decrease does not affect the sensitivity for frequencies below our chosen maximum value of 6,000 cycles per second, to an appreciable extent.

With television, of course, where higher frequencies are required, this is a different matter and would require further consideration, but here with sound reproduction it is fairly simple to keep the sensitivity reasonably constant over our working range.

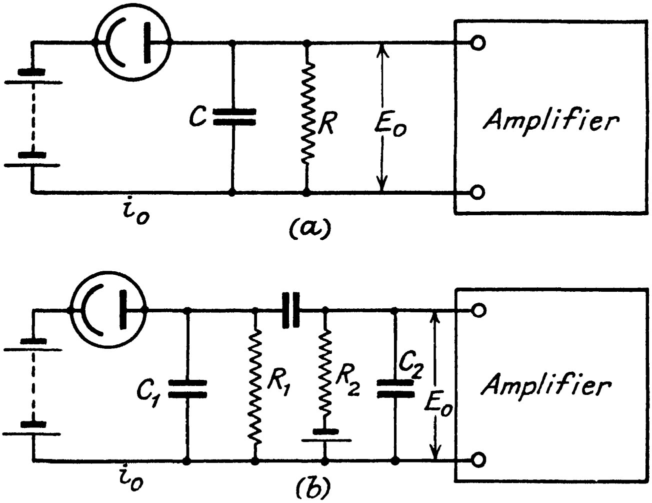


FIG. 61. CELL-COUPLING CIRCUITS

In Fig. 62 the sensitivity variation is given for a sound head coupling with several values of R between the insulation value of the grid of the valve and a 2 megohm resistance.

In the case of a well-designed photocell coupling which was required to operate at up to 10,000 cycles per second, the value of C was actually measured as 50 micromicrofarads (which, by the way, is very small for this type of amplifier), and R was chosen as 250,000 ohms. Here, then, the decrease in voltage output at 10,000 cycles due to the shunt capacities works out at 10 per cent, of which the capacity of the cell itself (5 micromicrofarads) accounts for 1 per cent. But this is a good quality amplifier with very short connections between the cell and valve, and a very low amplification valve in the first position.

As an example of the amount this capacity can influence the response, measurements taken on a commercial sound head have indicated that at 8,000 cycles using 250,000 ohm resistance the drop was of the order of 60 per cent, and as it is usual to find a 2 megohm resistance in this position, the loss at 8,000 cycles might easily be 22 decibels.

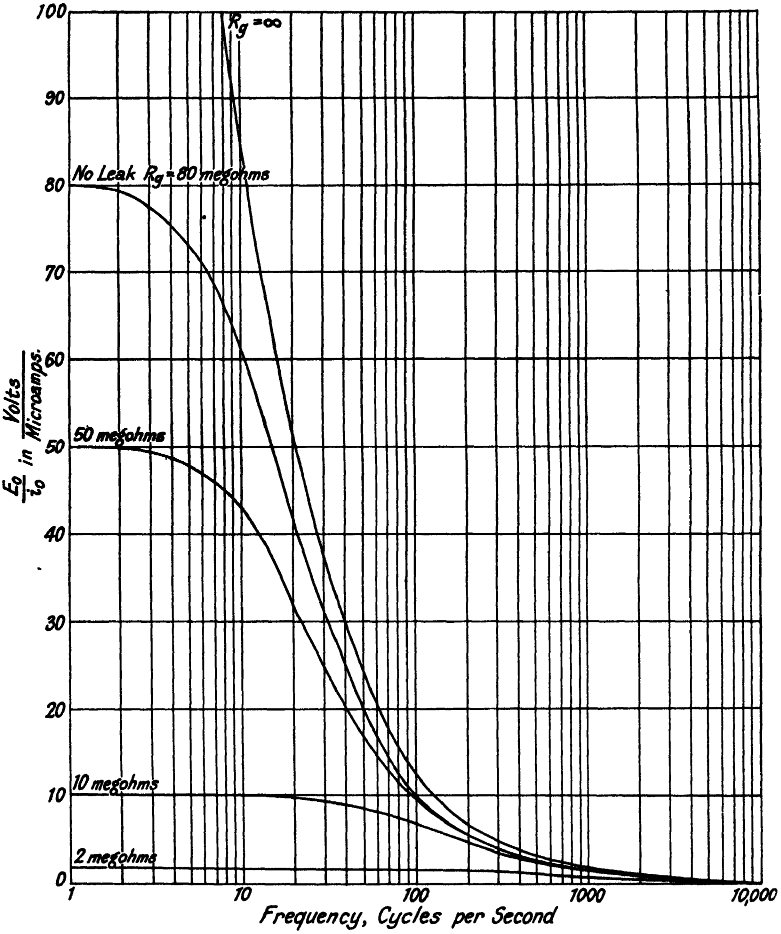


FIG. 62. FREQUENCY VARIATION WITH COUPLING RESISTANCE

It is therefore necessary to use as low a value of coupling resistance as possible, to have very short connections between the cell and the grid of the first valve of the amplifier, to have a low amplification valve in this position in order to reduce the input impedance, and

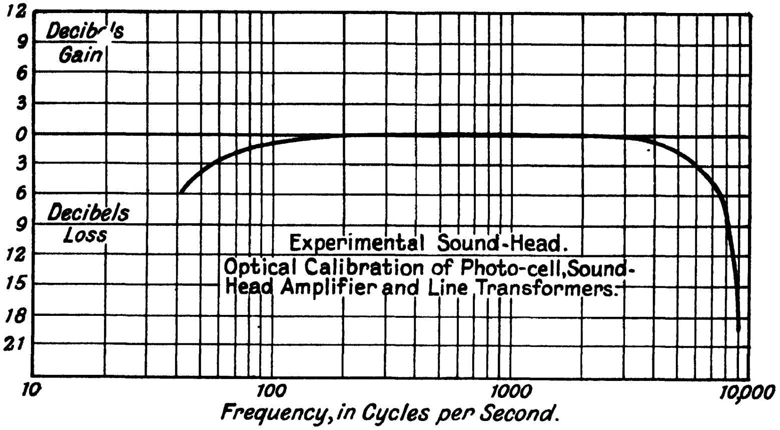


FIG. 63. FREQUENCY CHARACTERISTIC (CELL AND SOUND HEAD)

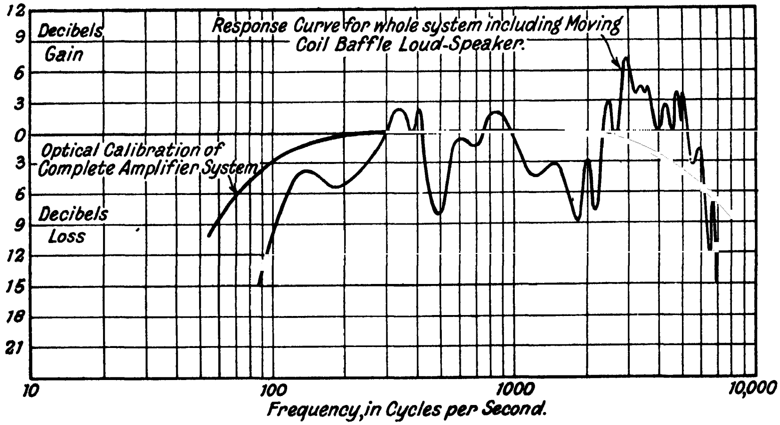


FIG. 64. FREQUENCY CHARACTERISTIC (CELL AND SOUND HEAD WITH LOUD SPEAKER)

to keep the earth screen as far away from the cell and its connections as is conveniently possible.

If, as is usual in resistance capacity coupling followed in radio practice, the grid of the valve is not coupled conductively to the cell resistance, but receives the voltage E_0 through a coupling condenser as in Fig. 61(*b*), then R is roughly the resistance of R_1 and R_2 in parallel, and C in the equation is $(C_1 + C_2)$. R_1 is then made low in value (say 250,000 ohms) to give the required frequency characteristic, and R_2 is chosen fairly high of the order of 2 megohms so as not to reduce this value appreciably.

It might be of interest to close this section with reference to some measurements taken on the experimental sound head, which has been referred to at several points throughout the chapter.

This equipment was operated entirely from the alternating current mains (frequency 50 cycles) with an infra-red filter as described, on the light, and consisted of a preliminary sound head amplifier, and a two-stage power amplifier giving an output of 30 watts. The sound head amplifier consisted of a single stage with the early type of caesium-on-silver cell which was the only type available at that time, and due to the characteristics of these cells (see Fig. 60A), it was found unsatisfactory to use a triode owing to the high input impedance, very seriously reducing the high frequency response. A screened grid valve was therefore used with a low impedance in its anode circuit. Also a high inductance choke was included in series with the coupling resistance in the cell circuit to raise the impedance at the higher frequencies and thus compensate for the drop due to the capacities. The remainder of the circuit calls for little comment, but frequency response curves are given to show that up to the loud speaker quite good reproduction can be obtained from sound-on-film records.

These curves indicate a reasonably level output between 50–6,000 cycles per second. The cut-off at 6,000 cycles is sharp because it must be remembered that the amplifier has to be used to reproduce sound-on-disc recording as well as the sound-on-film, and above this frequency the needle scratch noise becomes very serious. The low frequency cut-off is advantageous, as the elaboration of the smoothing units from the mains rectifiers can be considerably reduced in consequence.

When the sound pressure characteristic of the loud speaker is added to the amplifier characteristic, the curve shown in Fig. 64 is obtained, which although appearing doubtful on paper operates extraordinarily well at the high sound level of reproduction required for this class of work.

CHAPTER VII

PHOTOTELEGRAPHY

THE electrical transmission of pictures has only become a commercial proposition in recent years, but the fundamental ideas are actually as old as any other conception of transmitting signals from one place to another by electrical means. A historic survey of the early progress is extremely interesting, but space permits of only scant reference to it here, since we are concerned with modern developments, and in particular the part played by the photocell in them.

All the systems hereafter described have now passed beyond the experimental stage, and many are in daily operation for the transmission of newspaper illustrations. How good the results are can be realized by inspection of the reproduction in pictorial newspapers and magazines.

The amount of detail transmitted is well up to the standard of a good half-tone block, and it is exceedingly difficult to distinguish the transmitted picture from the original, so perfectly are the systems controlled and operated.

In 1842, Alexander Bain, an English physicist, first proposed sending pictures from one place to another through the medium of electrical signals transmitted over wires. He arranged two identical pendulums swinging together, one as a transmitter, the other as a receiver, so that if one reached the end of its swing before the other, it was held electrically until the second pendulum completed its swing, whereupon both were allowed to start a new swing together. At the transmitting station, the pendulum carried a small stylus which made electrical contact at appropriate points on a specially prepared original. The pendulum at the receiving end carried a fine contact across a chemically prepared paper which was discoloured by electrolysis due to the currents received as signals from the transmitter, and thus traced out a replica of the original. Pioneer as it was, this crude arrangement contained all the essentials of successful picture transmission. There was synchronization between transmitter and receiver, and a form of scanning of the original, which enabled the identity of any particular point on it to be re-established at the receiving end. Yet in spite of this early realization of these fundamental principles, the development of a satisfactory commercial system of picture telegraphy long eluded the many workers who investigated the problem. It was soon shown that a really efficient and economical solution was going to prove more difficult than either telephony or telegraphy, because no half-measures could be tolerated in the results. The public would naturally demand perfection from the start of the picture service if this was to compete successfully with ordinary postal transmission. For it must be borne in mind that the rental of land lines for this purpose is an expensive item since each transmission takes at least several minutes, and high quality telephone lines are essential.

Practically every system of phototelegraphy has one common basis, namely, that of dividing the picture into a large number of small areas, each of which is examined in turn by a photocell. An electric signal corresponding to the light response of each of these small areas is produced and sent to the distant point where the reverse process takes place, and a replica of the original photograph or drawing is produced. The dividing up of the original into small areas is somewhat akin to the half-tone process of preparing a picture for printing in a newspaper. The usual newspaper half-tone block is built up of rows of dots about 65 to the inch, which corresponds to over 4,000 dots per sq. in. It has been shown that at least 5 density steps, including black and white, are essential for the necessary gradation of tone to give recognizable reproduction, so that the telegraphic process must show the ability to transmit from one point to another in identifiable shape at least 4,000 impulses per sq. in. of picture, each of which may be one of the five density steps. On the usual telegraphic circuits, the fastest speed is about 75 pulses per second, so that a full-plate picture, would at this rate, take about 50 minutes for transmission. It is clear that the three main difficulties which confront successful transmission are the number of impulses the apparatus must be capable of transmitting, the accuracy of reproduction and synchronization, and the time required for each picture. These inherent difficulties naturally led to a search for a picture "shorthand." One method which has been investigated by the R.C.A. in their Photoradiogram transmitter, is to arrange a variable spacing of dots, all of which are of the same density. It is clear that a group of dots widely spaced will give an impression of a nearly white surface, whereas closely spaced, they will approximate to a black surface, and any gradation between these two extremes can be attained by varying this dot spacing. The picture to be transmitted was first prepared in the form of a photographic negative, and was wrapped round a glass cylinder. The source of illumination was fixed inside the cylinder and the light directed by lenses through the negative so that an image of a small portion of the negative was projected on to the photocell point by point. The variable spacing was produced by the number of impulses sent per unit length of the scanned negative on the drum. Subsequent amplification was carried out on the lines of that shown in Fig. 65, the plate current of the valve being supplied by a condenser which was charged at intervals, arranged in such a way that as soon as the condenser charge has diminished to a certain value, the plate battery was again connected in circuit, and the condenser recharged to its maximum capacity. To do this, a large battery *C* is connected to the H.T. side of the condenser so biased that the plate voltage must fall below a given value before a second valve stops drawing plate current through its anode circuit. This second plate current is carried through a relay, and while the relay coil is energized the contacts are open, but when de-energized, the contacts bring the charging battery into circuit, and a pulse is sent to the condenser. Obviously, therefore, the time interval between the successive charges of the condenser is determined by the rate of flow of the plate current of the first valve which is directly controlled by the photocell. The light intensity on the cell is thus made directly to influence the rate of closing of the relay. This relay can operate audio frequency modulation on telegraph lines or radio transmission. In addition to the variable light coming through the negative from the source of illumination, a small auxiliary lamp is used to enable the cell to be operated at the most satisfactory point of its characteristic. Synchronization between transmitter and receiver was secured by means of a valve-maintained tuning fork with clock control, as a further check. The receiver comprises a direct ink record on paper. The fact that the transmitter is of the nature of a trigger circuit, the current being either on or off, makes reception easier than in the case where analysis of current variation has to be made in the presence of line disturbances which are common to all cable transmissions. For a similar reason, fading in the case of radio

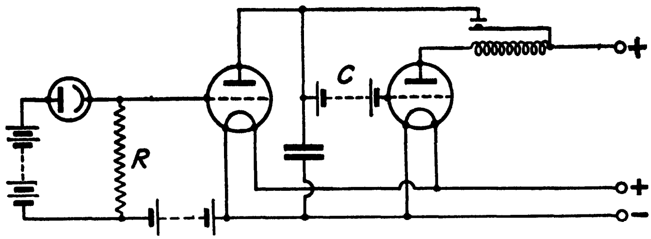


FIG. 65. "DOT" TRANSMISSION SYSTEM
(*Radio Corporation of America*)

transmission is of less consequence. On several occasions transatlantic transmissions have been successfully carried out by this system.

It appears highly probable that it may soon be possible to receive the picture by this process in the form of a half-tone dot negative which can be used without further processing to print down direct on to the zinc plate for etching. Dr. Ives has already described a method and apparatus for working in such a manner, and the results obtained show convincing evidence of its possibilities. It has also been suggested by him that the method may be carried further in a printing works in such a way as to supersede the use of customary half-tone camera and screen by using a transmitting and receiving unit working in synchronism side by side, so that the photograph would be placed on the transmitter and then taken off the receiver as a half-tone negative. It should be possible to print newspapers by offset lithography or some analogous method of surface printing so that the negative would be printed down direct on to the metal plate and then go straight to the printing machine, thus eliminating the process of etching, making up formes, and stereotyping. A considerable economy in time would therefore be effected.

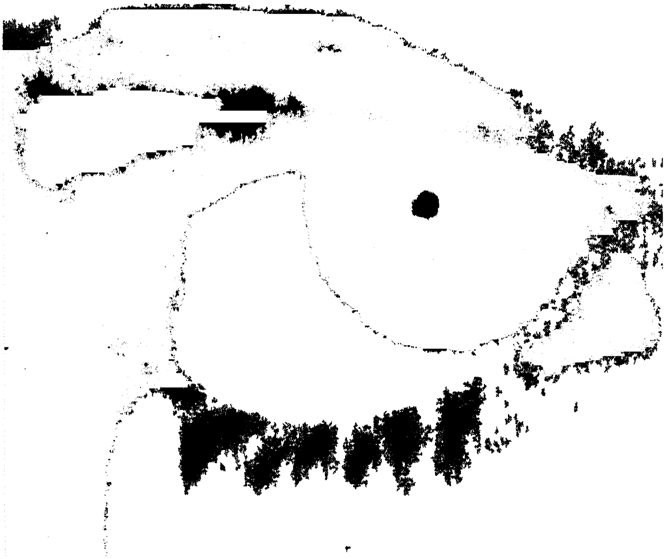


FIG 66 ENLARGEMENT OF RECEIVED IMAGE (× 12)

The present requirements of high-speed transmission have practically ruled out, from considerations of the time involved, those systems which require specially prepared originals, and in consequence in all commercial work the original picture, either as a negative or positive, is used on the transmitter. The photoelectric currents are produced either by light passing through the negative or by that reflected from the positive. In most cases the picture is mounted on a drum which rotates, while the light beam moves axially, the whole area being scanned in the form of a helix, the motion being similar to that of the Edison phonograph stylus. An enlargement of a received photograph shows this very clearly (Fig. 66). The original picture was scanned at ten lines per millimetre, and on this the lines can scarcely be resolved by the eye except with the aid of a lens.

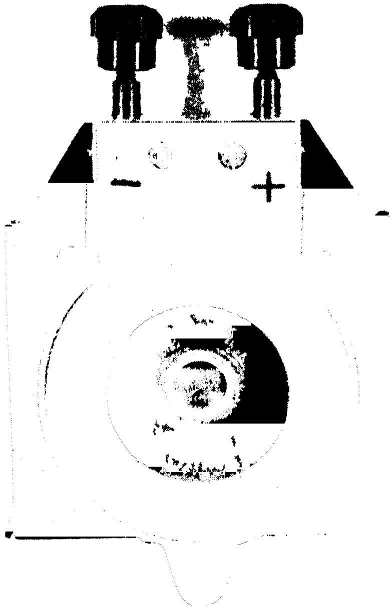


FIG. 67A. THE SIEMENS KAROLOUS CELL IN HOLDER
(Siemens Schuckert (Gt Britain), Ltd)

If a positive is used in the transmitter, trouble may be experienced owing to the small amount of light reflected from the surface. Hence the necessity of great care in the design of an efficient optical system. Generally one of two methods is used to utilize as much of the light reflected from the surface as possible. In the first method a small portion of the positive is illuminated by a concentrated beam of light and a small part of the illuminated area picked up by a lens system which directs it by reflection on to the photocell. Alternatively, the size of the scanning spot may be adjusted to the required dimensions, and the reflected light collected by a specially shaped photocell, as in the Siemens Karolous system. Fig. 67A shows the

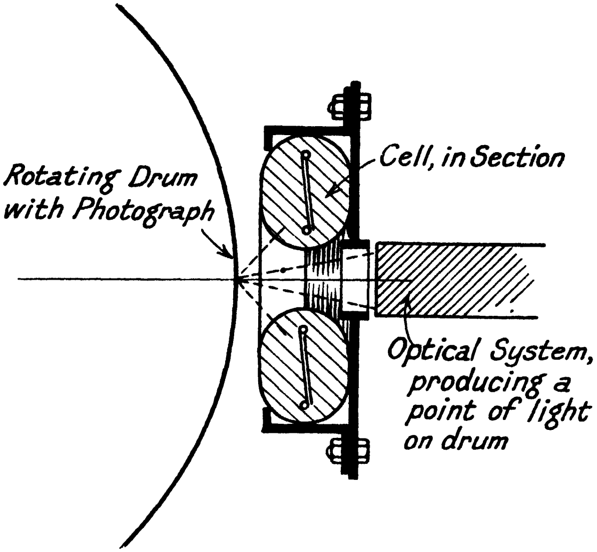

Rotating Drum with Photograph
Cell, in Section
Optical System, producing a point of light on drum

FIG. 67B. OPTICAL SYSTEM FOR SIEMENS KAROLOUS CELL
(*Siemens Schuckert (Gt Britain), Ltd*)

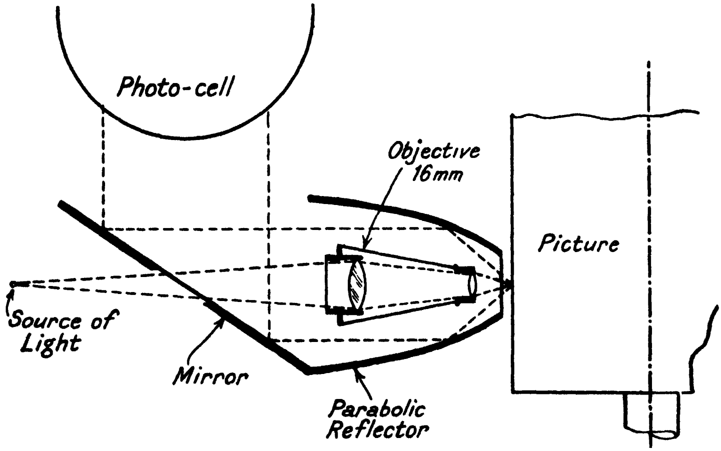


FIG. 68. OPTICAL ARRANGEMENT—WESTINGHOUSE SYSTEM
(*Westinghouse International Electric Co*)

type of cell used in this system, and Fig. 68 the optical arrangement used by the Westinghouse Electric Co. It is clear that any difference which exists in the efficiency of the optical arrangements can generally be made up in the amplifier portion of the transmitter. It is proposed now to outline three different types of transmission which have been used in this country.

The Fulton System.

A very simple and effective system of picture telegraphy was invented by Mr. Otto Fulton, and a good deal of development has been carried out on it in co-operation with Messrs. W. Watson. For some considerable time pictures were transmitted regularly by this system over broadcast channels, and engaged the attention of wireless amateurs in this country and on the Continent. To most wireless enthusiasts, the receiving apparatus or Fultograph was fairly familiar, but few had the opportunity of inspecting a transmitter. In the original transmitter, the picture to be sent was photographed through a line screen and transferred to a sheet of copper foil in a manner similar to the gum bichromate process commonly used in making half-tone blocks for illustrations. An image of gum deposit was produced on the copper foil in which the white parts of the original picture consisted of wide black lines almost touching one another, while the dark portions were narrow lines of gum deposit or actually bare copper. Gum deposit being a fair insulator, the copper-plate was clipped round a glass cylinder with the line image parallel to the axis. This was rotated in contact with a metal point in like manner to the wax record of a phonograph. Lines forming the image were spaced 50 per inch, and the picture was accordingly finely analysed. As the insulated lines passed under the needle a local circuit was interrupted, and pulses of current of the order of 150 or more per second, but of varying duration, were passed on to the transmitter. Wave trains of corresponding duration were radiated, and when tuned in at the receiver were heterodyned into damped waves by reaction or by a separate valve oscillator. After amplification and rectification, the received signals are passed on to the picture receiver, and the current pulses correspond exactly in duration with the periods of conductivity between copper foil and the stylus at the transmitter. The receiving cylinder carries an absorbent paper soaked in a solution, and electrolysis of the solution by the current passing from the stylus makes a visible record of the picture. Bare portions of the copper image produce at the receiver a dark stain, the depth depending on the width of bare copper line under the transmitting stylus at that instant. The production of the carrier wave can be attained by causing the insulating lines on the copper foil to interrupt an audio frequency oscillating circuit rather than control directly the C.W. trains of the transmitter. Fig. 69 shows how excessive bias prevents the flow of anode current when the grid circuit is broken. The pulses of audio frequency current thus set up are passed into the modulating apparatus of the broadcast station. If the introduction of an audio frequency carrier is adopted, there is no point in preparing a gum line image, hence the introduction of the photocell in the later forms of transmitter. Fig. 71 shows one of the later machines, the right-hand unit being the amplifier, and the left unit the photoelectric gear. The vertical cylinder contains a small low voltage projector lamp, which directs light vertically downwards through a lens system through the picture, which in this case is the actual photographic negative, on to the cathode of the photocell, which is mounted concentrically with the axis of the transparent cylinder. The use of the negative simplifies the apparatus enormously. Fig. 70 shows a special type of photocell designed for use with this transmitter. Synchronization is attained by sending out once during each revolution of the drum a modulated wave train similar to the now defunct tuning note, or better still, a C.W. train free from modulation. The maximum time of this will be only a fraction of a second, and this controlling wave train can be conveniently sent out during the interval in which the stylus passes over the joint of the folded negative. It is actually

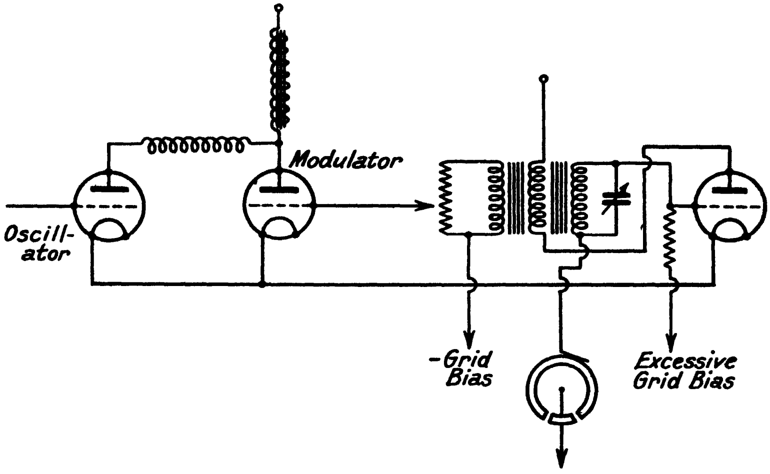


FIG 69 FULTON TRANSMITTER CIRCUIT DIAGRAM
(*Wireless World*)

created by the metal strip covering the fold. At the receiving end, as soon as the stylus passes over the clamping strip, the output valve is connected to a relay and the magnetic clutch driving the cylinder is released, the cylinder being arrested by a catch lever falling into a slot on the cylinder. The synchronizing signal controls the anode current, releasing the clutch and holding the drum. As soon as the drum stops, the re-engagement of the clutch sets the cylinder in motion. The receiving cylinder, which is running slightly faster than the transmitter, is held briefly and released again by a signal from a conducting bar or, if necessary, from a cam on the cylinder of the transmitter.

This short outline will suffice to indicate the extreme simplicity of the apparatus compared with other systems now in general use for phototelegraphy. The transmitter, Fig. 71, is actually driven by a clockwork motor similar in principle to that used in the ordinary gramophone. Alternatively, by a simple change of motor, it can be made to operate from supply mains. The necessity for soaking the paper to receive the image in a chemical solution before use is, of course, a drawback, and tends to make reception a rather messy business, but otherwise some excellent transmissions have been carried out with this apparatus. The later types of receivers were supplied with absorbent paper already treated, so it was only necessary to soak it in water before use. As received, the wet image is a chocolate colour, and for newspaper reproduction is photographed in this condition. If allowed to dry, it assumes an orange tint which is much less pleasing. Admittedly, the more elaborate systems in use by the leading newspapers give superior reproduction of detail, but with a good negative and favourable conditions, the difference may be quite small. It is very unfortunate that the system has not received continued attention, but it seems obvious that for such cases as the transmission of weather charts to distant land stations,

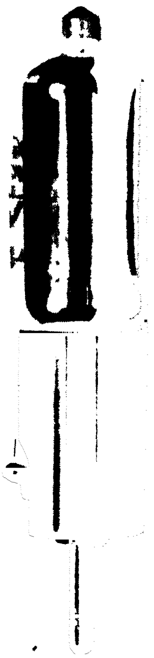


FIG. 70. SPECIAL PHOTOCELL FOR FULION SYSTEM

FIG. 71. FULTON TRANSMITTER

to aircraft, etc., this system, or some modification or development of it, will come into being again.

The Belin System.

Fig. 72 shows a schematic outline of the Belin transmitter, which is in daily use in this country by the *Scotsman Press* in their exchange of pictures between London and Edinburgh. Considerable attention has been paid here to securing the greatest detail in definition, and contrary to expectations, it has been found by the manufacturers, that above a certain point, there is no gain in definition in the received picture by increasing the number of elements into which the positive is divided. The scanning is limited to approximately 135 lines per in., corresponding to 18,200 points per sq. in. The lamp (Fig. 72) is of the low voltage automobile type, giving a beam of light which is interrupted by a rotating disc having a number of circular holes in its periphery. This disc is motor driven and gives a carrier frequency of about 1,300 per sec. This rapidly interrupted light produces, in the photocell circuit, rapidly intermittent currents

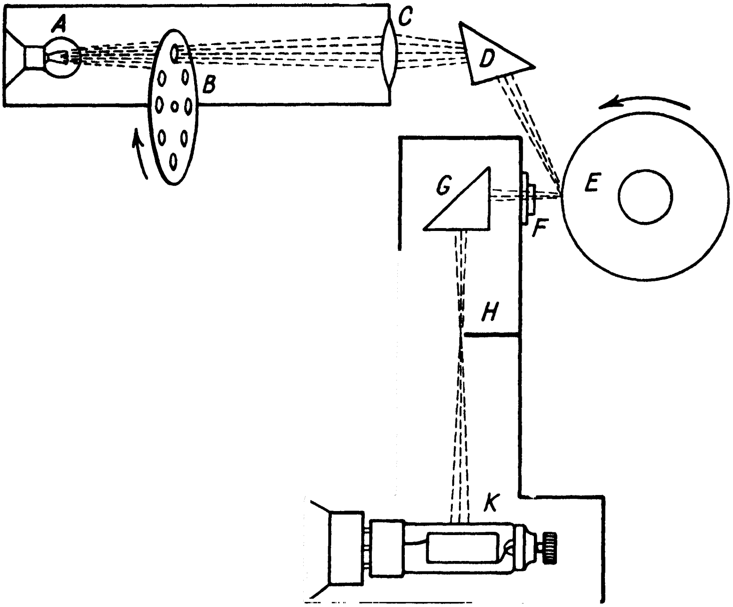


FIG. 72. DIAGRAM OF OPTICAL SYSTEM OF BELIN PICTURE TRANSMITTER

(*Etablissements Belin, Paris*)

capable of amplification by valve circuits at a frequency which is suitable for transmission over telephone circuits, through cables, and repeaters. Upon this carrier frequency is superimposed the modulation due to the whiteness of the successive points of the picture as they pass under the pencil of light, the diameter of which is about 0·008 in. By means of the optical system employed (micro-objective of magnification 8) a magnified picture of the point is thrown on the cell cathode. The photoelectric current is subsequently amplified by transformer-coupled stages. Fig. 73 gives an outline of the circuit employed, and Fig. 74 a general view of the transmitter and control panels. The picture about to be sent over the line is clearly seen on the left-hand side of the apparatus. The control panels have been designed to render manipulation as easy as possible, and the number of controls have, for this reason, been reduced to a minimum. Numerous safety devices to prevent mistakes being made and to secure faithful relationship between picture tone and line current, have been introduced. Owing to attenuation on the transmission lines and to the weakness of the signals in the case of radio transmission, further amplification of the signals at the receiving end is essential. After subsequent rectification, the signals are sent through an oscillograph, the mirror of which reflects light from an independent source of illumination through a specially

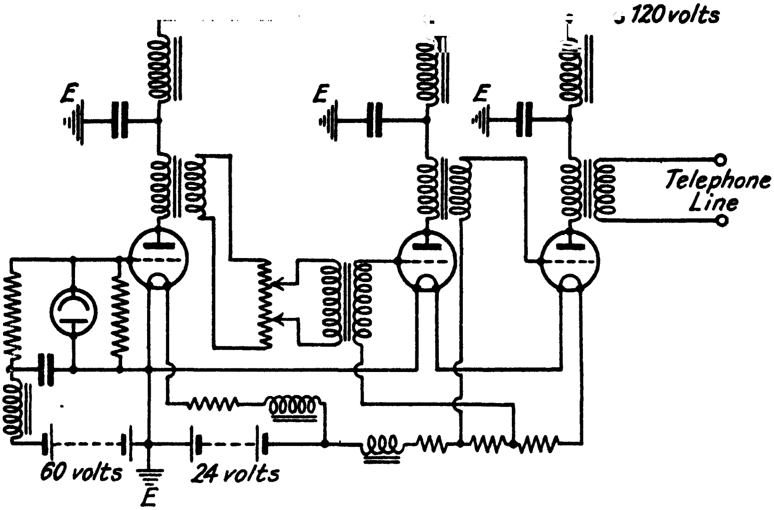


FIG 73 CIRCUIT OF THE BELIN TRANSMITTER
(*Etablissements Belin, Paris*)

shaped slit on to a drum carrying the sensitive photographic paper. The receiving drum is, of course, enclosed in a light-tight chamber. Adjustments can be made so that when the incoming signal is a maximum, the amount of light passing through the slit is either a maximum or a minimum, which will give a white point on the sensitized paper, and either a positive or a negative can thus be formed simply by adjustments at the receiving end. Synchronization between the rotating drums is obtained by coupling the receiving motor to a synchronous or phonic motor operating on a constant frequency of 600 cycles per sec. Provision is made against errors introduced by change of temperature, and stroboscopic checks on synchronization are made at the beginning of each transmission. A receiver is fitted to the same bedplate as the transmitter so that the operator can receive his own picture and check all mechanical adjustments. The time required for the transmission of a picture 5½ × 7½ in. is about 11 minutes.

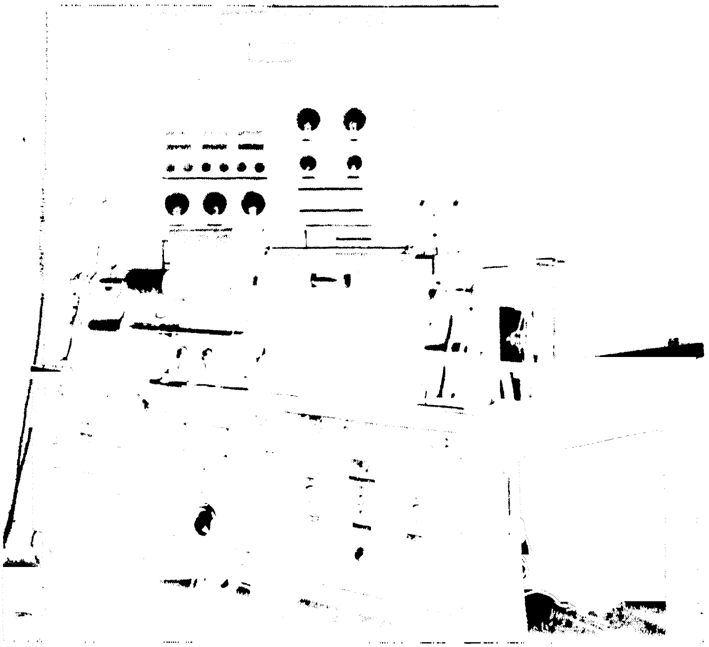


FIG. 74. BELIN TRANSMITTING APPARATUS
(*Etablissements Belin-Paris*)

Bartlane System.

This system differs from those previously described inasmuch as the actual transmission is carried out over ordinary telegraph wires, using the codes generally employed for transmitting verbal messages. The picture is first coded into an ordinary message on perforated paper at the transmitting end, after which the tape is passed through an ordinary telegraph transmitter, and a similar perforated tape made at the receiving end. The actual tape constituting the

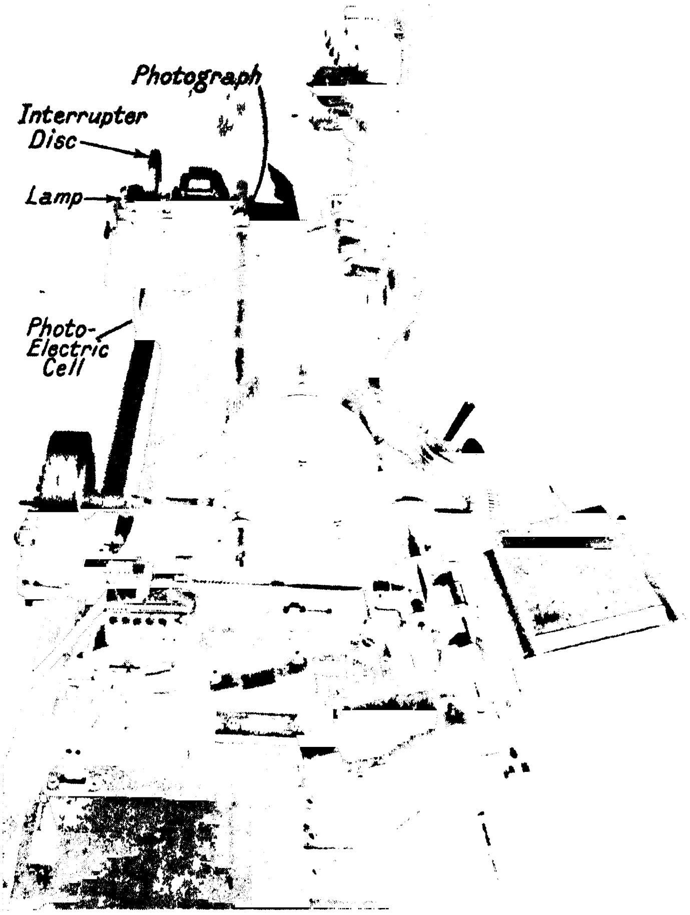


FIG 75 GENERAL VIEW OF BARTLANE APPARATUS
(*Daily Mirror*)

transmitted picture cannot be distinguished from a message in code. At the receiving end the new tape is passed through a piece of apparatus in which the perforations act as shutters or apertures controlling the amount of light which passes from a lamp on to a sensitized film.

Black and white drawings are very easily transmitted, as it is only necessary for the punch magnet to perforate the tape when the spot of light is on a white portion of the picture and not to perforate it when the spot of light is on a black portion. The prepared tape in such a case consists of single perforations, or blanks, according as the scanned point is white or black. It is clear that in the initial preparation of the tape the latter must move uniformly with the rotation of the cylinder, and the tape perforating machine must be controlled accordingly.

The satisfactory reproduction of a photograph as distinct from a black and white drawing depends upon a means of recording several tones as distinct from black and white. Actually, five tones between black and white were decided upon, and by means of selective relays five values of current were distinguished corresponding to the five picture tones.

It is clear that by elaboration any number of tones could be arranged, the larger the number within certain limits, the finer the gradation in the received picture but, of course, with the introduction of considerable mechanical and electrical complication. Thus, the tone of a particular point on the picture is represented by the number of relays that operate. If the picture point is black, no relays operate; if white, all five relays are brought into action. A grey tone will cause one or more relays to operate according to its tone value. The five unit telegraphic code was chosen in order to simplify the process of perforation and to permit the use of high-speed telegraphy.

The marking contacts of the five relays were connected to the five punch magnets of the tape perforating machine, so that the number of holes punched transversely across the tape indicated the number of relays that had operated.

Fig. 76 illustrates the circuit for this method of operation. The relays are of the standard Post Office type, and have two windings, one being supplied from a battery or from D.C. mains through a suitable resistance. This current holds the relay in the "spacing" position and will be referred to as the retaining current. The current from the amplifier passes into a rectifier, thence through the other winding of the relay in such a direction as to bring the relay into operation. As soon as the magnetic effect of the amplified

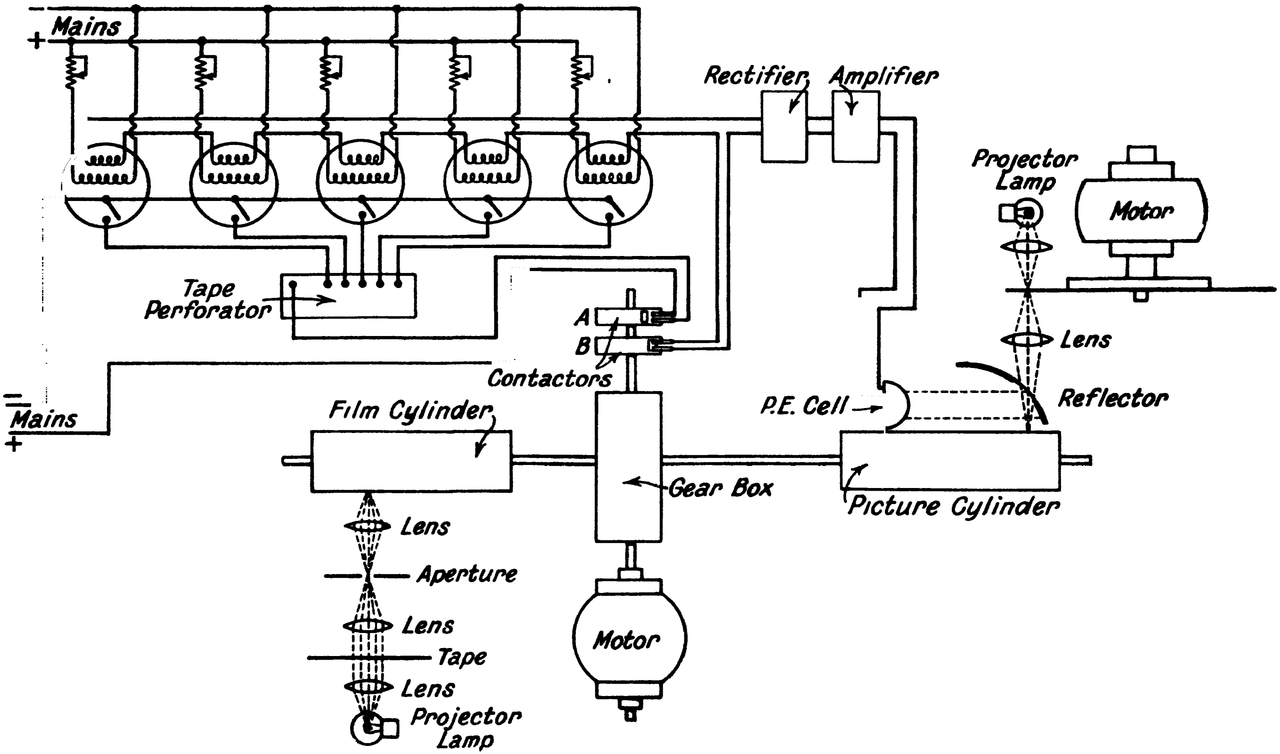


FIG 76 CIRCUIT DIAGRAM OF THE BARTLANE SYSTEM

current exceeds that of the retaining current, the relay moves over to the "marking" position. Suitable adjustment of the current in the retaining windings allows any one of the relays to operate at a predetermined current from the amplifier. The amplified current is interrupted by a contactor marked *B*, operated mechanically from the gear box driving cylinder, and by this means the relays are allowed to reset at intervals, thereby automatically dividing the photograph into a series of imaginary areas. The gearing between the contactor mechanism and the screw driving the cylinder is such that the contactor operates each time the surface of the cylinder has revolved a distance equal to the diameter of the spot of light. A second contactor *A*, Fig. 76, interrupts the supply to the punch magnets after each perforation, thus preventing sparking at the contacts of the relay.

The apparatus for reproducing the photograph from the punched tape is very simple, and consists of a cylinder connected to a screw and carrying a sensitive film wrapped round its surface. A motor drives this cylinder through a gear box, the same motor being used to drive either the transmitting cylinder or the receiving cylinder, as desired. The perforated tape passes between the projecting lamp and the film, so that the amount of light falling on the film depends on the number of holes lying in a row across the tape, there being five adjustable holes immediately behind the tape and in the path of the beam of light. A full size illustration of a sample of tape is given in Fig. 77.

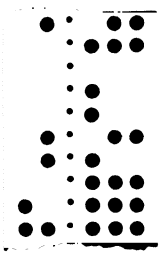


FIG. 77. SAMPLE OF PERFORATED TAPE

Single-frequency System.

With a view to increasing the amount of detail obtainable in the photograph, an improved system in which fifteen tones are selected and coded into fifteen combinations of the five unit telegraphic code has been developed. To do this it is necessary to devise an arrangement of relays by means of which fifteen combinations of punch magnets can be brought into operation, corresponding to the fifteen tone values.

The principle will be understood from a description of the method of controlling the punch magnets. Actually, seven relays are employed to operate five punch magnets as shown in the table (page 131). The relays are numbered and the numbers also represent the comparative values of amplifier output current at which the relays will operate. For instance, relay 8 will operate when the amplified current is eight times that required to operate relay No. 1, and twice that required to operate relay No. 4. There are two groups of operating windings. Those of relays 1, 2, 3, are in circuit with a sliding contact marked *B*, and relays 4, 8, 12 and 4*B*, in series with a similar contact *C*. Arrangements are so devised that relays 4, 8, 12 are pre-selectors to relays 1, 2, 3, so that by means of a special arrangement of resistances the current values at which relays 1, 2, 3 (Group II) operate are increased in three successive stages as relays 4, 8, 12 (Group I) operate, respectively. Relay 4*B* is an auxiliary relay whose windings are respectively in series with the corresponding windings of relay 8.

We can imagine the amplified current to be graded into fifteen steps according to the tone of the picture element, tone value "one" corresponding to a black point on the picture, tone value "fifteen" likewise corresponding to a white point. Tone value "two" will correspond to twice the amplified current of tone value "one."

The relays are of the standard P.O. type and have two coils, one carrying the output or marking current, and the other being a control coil. The relay is given a slight bias towards the "marking" position, so that it will move to this position as soon as the magnetic fields of the two windings balance. With all the relays set, the control currents are adjusted to produce the values of magnetic effect given below.- A relay will operate when the current in the marking winding produces an effect equal and opposite to that of the control circuit.

Current Corresponding to Tone Value	Relay	Punch Magnet
4	4	4
8	8 & 4*B*	5
12	12	4
1	1	1
2	2	2
3	3	3

The operation of relay 4 by means of resistances suitably arranged, causes the control current in relays 1, 2 and 3 to increase by an amount equivalent to the current in relay 4, so that if the current flowing in the operating coil when Group I relays are connected to the amplifier is sufficiently great to operate relay 4, that required to operate relays 1, 2, and 3 will be raised when Group II is connected to the amplifier. The condition after relay No. 4 has operated is as follows—

Current Corresponding to Tone Value	Relay	Punch Magnet
1 + 4 = 5	1	1
2 + 4 = 6	2	2
3 + 4 = 7	Group II 3	3

In like manner, when relay 8 operates, the control in relays 1, 2 and 3 is raised by a further amount equivalent to a current value 4. When the current in the operating winding is great enough to operate both relay 4 and relay 8, the current values to operate relays 1, 2 and 3 will be as follows—

Current Corresponding to Tone Value	Relay	Punch Magnet
1 + 4 + 4 = 9	1	1
2 + 4 + 4 = 10	Group II 2	2
3 + 4 + 4 = 11	,, ,, 3	3

In exactly the same way relay 12 raises the control in relays by a further amount equivalent to a current 4. The following table shows the combinations of holes punched in the tape corresponding to tone values—

Tone Value	Relays Operated	Position of Perforations Punched in Tape					
Black	None	3	4	·	5	1	2
1*x*	1			.		o	
2*x*	1 + 2			.		o	o
3*x*	1 + 2 + 3	o		.		o	o
4*x*	4		o	.			
1 + 4 = 5*x*	4 + 1		o	.		o	
2 + 4 = 6*x*	4 + 1 + 2		o	.		o	o
3 + 4 = 7*x*	4 + 1 + 2 + 3	o	o	.		o	o
4 + 4 – 8*x*	8 + 4*B* + 4			.	o		
1 + 4 + 4 = 9*x*	8 + 4*B* + 4 + 1			.	o	o	
2 + 4 + 4 = 10*x*	8 + 4*B* + 4 + 1 + 2			.	o	o	o
3 + 4 + 4 = 11*x*	8 + 4*B* + 4 + 1 + 2 + 3	o		.	o	o	o
4 + 4 + 4 – 12*x*	12 + 8 + 4*B* + 4		o		o		
1 + 4 + 4 + 4 = 13*x*	12 + 8 + 4*B* + 4 + 1		o		o	o	
2 + 4 + 4 + 4 = 14*x*	12 + 8 + 4*B* + 4 + 1 + 2		o	.	o	o	o

The receiver is the same as that used with the five tone picture except that, of course, there is a difference in adjustment of the sizes of light aperture behind the tape in order to secure uniform differences in exposure of the film. The adjustments may be made experimentally by trial or could be calculated if the sensitivity curve of the film is known.

Two-frequency System.[1]

It will have been gathered from the description above that the tone of an element of the photograph under the light spot is determined by comparing the current produced in the photocell with that from a separate supply. It is obvious that in order that this current balance shall represent the same picture tone throughout the time of transmission, the source of illumination, the applied voltages and characteristics of photocell and amplifier must be constant. This can be secured only by using heavy batteries, the upkeep costs of which are high. In order to overcome these troubles a two-frequency system has been developed.

Fig. 78 shows the photocell illuminated by two beams from the same source, one beam called the "Picture Illumination" performing the function previously described, the other the "Standard Illumination" being directly incident on the cell. A separate circle of holes on the rotating disc interrupts each beam. The holes are concentric but differ in number, giving currents of two separate frequencies which are both subsequently amplified. The amplitudes of the picture current depends on the tone of the picture, but that of the standard is independent of the picture. After rectification, the standard frequency source is employed to supply current to the control or spacing windings of the relays in exactly the same manner as the D.C. supply previously described in the single-frequency apparatus.

If we consider any particular picture element it will be clear that any change in voltage on the photocell, or source of illumination, will equally affect the amplification of both currents, and the current difference which determines the operation of the relays will be unaffected. It is thus possible to dispense with batteries and feed the apparatus entirely from supply mains, and this only necessitates an occasional check on the performance of the relays by perforating a length of tape from a uniformly graded black and white paper, thus ensuring the correct combination of perforations. A number of pictures have been successfully transmitted from New York to London by this system, and have appeared in various issues of the

---

[1] Developed by Mr. J. Dalton in conjunction with the *Daily Mirror*.

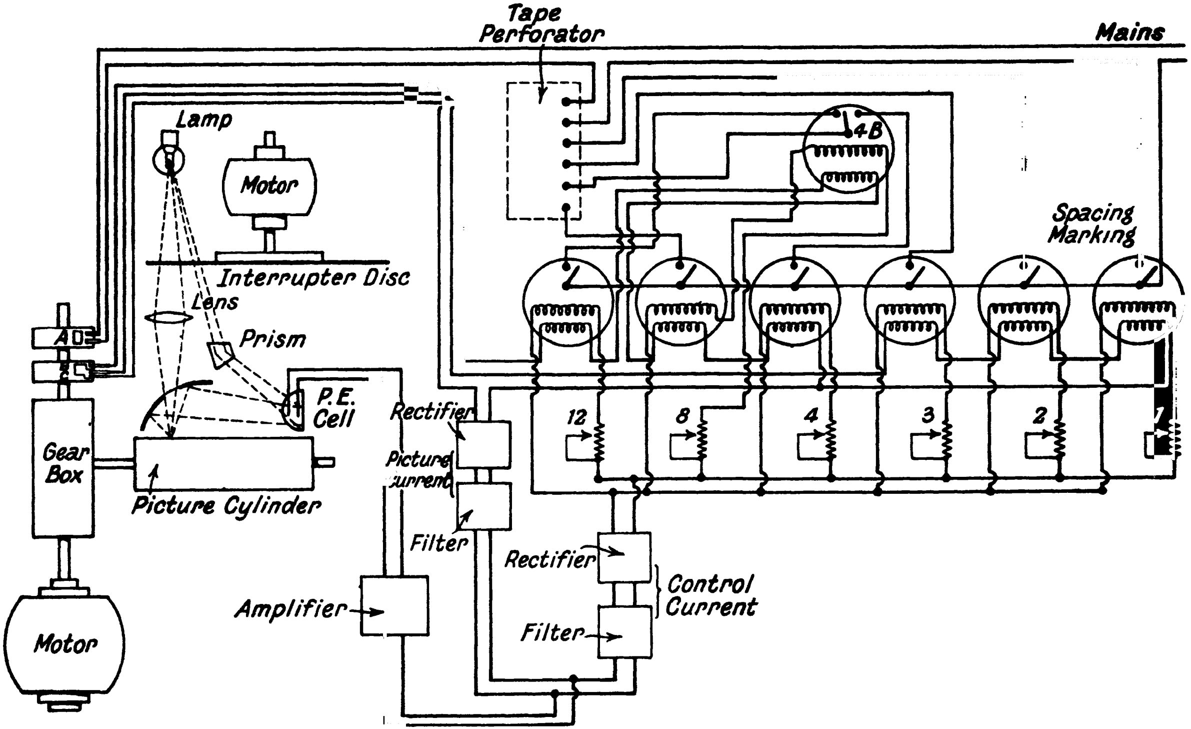


FIG. 78. CIRCUIT DIAGRAM OF TWO-FREQUENCY SYSTEM
(*Daily Mirror*)

Daily Mirror. Pictures have also been transmitted from Buenos Aires to Europe by radio on a wavelength of 16 metres by the Transradio International Company of Argentina.

A picture, 16 in. square, is divided by this system into about 60,000 elemental areas, and the length of the telegraph message, therefore, consists of 60,000 dots, assuming the transmission is for a black and white drawing. In photographs, each elemental area is coded into a letter of the five unit telegraphic code, and in consequence is transmitted in the time occupied to transmit five dots. A 4 in. × 4 in. photograph, therefore, takes five times as long to transmit as the same area black and white sketch. The photographs sent by radio from Buenos Aires to Berlin were transmitted at 400 words per min., the total time taken being 150 minutes.

This system of transmission has many advantages. Once a tape has been correctly perforated, it is permanent and permits of easy repetition in transmission over the same or another cable line. In addition, the prepared tape can be run through a local receiving apparatus, and the sender is thus enabled to see exactly the quality of the photograph that will be received at the other end of the line. A special signal is transmitted at each revolution of the cylinder to mark the edge of the photograph. This facilitates restarting of the tape at the point corresponding to the interruption should the transmission be stopped for any reason. The tape can, if necessary, be cut into several sections and each be transmitted over a separate channel.

In the previous paragraphs, we have given a short description of the transmitters and as much of the receivers as is likely to be of general interest, of three essentially different systems of phototelegraphy, which are representative of their class. It must not in any way be assumed that because they are described here, they are better than other systems which differ in detail, but are fundamentally the same in principle. In fact, such systems, for instance, as the Bell system and the Siemens Karolous system, are used by leading newspapers, and the excellence of their transmissions is admitted by the most critical reader. So great have been recent improvements, that it is frequently impossible to distinguish a wired picture from the original without the aid of high magnification, and for this reason no attempt has been made here to reproduce two such illustrations for the purpose of comparison.

CHAPTER VIII

TELEVISION

Fundamental Principles.

EARLY experiments in television, or the transmission of animated scenes by means of electrical circuits, were for a long time handicapped through a lack of suitable light sensitive devices for translating the optical images into electrical impulses. Our previous chapter was devoted to a description of the principles and practice of the present-day picture telegraphy services between distant places, but television differs from facsimile telegraphy in that the received image cannot be recorded as a permanency since it has to convey the impression of movement. There is a rough similarity however between the fundamental operations, for in both systems the transmitted picture is divided by some mechanism into small elemental areas which have to be translated into electrical impulses by some form of light sensitive device. In picture telegraphy a full-plate photograph may require fifteen minutes for transmission, in television at least sixteen complete pictures have to be sent every second, the persistence of vision of the observer's eyes blending the individual pictures into a continuously moving scene. This is, of course, following the well-known principle of the cinematograph where sixteen, and with talking films twenty-four, complete pictures a second are projected on the screen in sequence, and the time lag of the eyes of the observers blends them together to give the illusion of a moving picture. If fewer than sixteen pictures follow one another per second, flicker becomes apparent, and the animation is unpleasant for the observer to follow.

It will be appreciated at once that in television, the number of elemental areas chosen to form the picture subdivision will be strictly limited by the available frequency band of the channel over which the transmission is to take place, and this has been found to be the limiting factor on all developments. Thus, for the transmission of a picture 5 in. × 7 in., if subdivided into elements corresponding to 100 lines per in., giving the same definition as in facsimile telegraphy, there will be 350,000 elements, and at a picture repetition of sixteen a second, the highest frequency of the transmission would have to be 2,800,000 cycles a second.[1] This is, of course, extremely fine definition, probably more than may be expected for many years, and it may therefore be considered the ideal transmission. When it is remembered that broadcasting of music and high quality speech only calls for a frequency band of 5,000 cycles a second, the difficulties of high quality television transmission become apparent. At present a daily service is being given in this country with quite good results, with a frequency band of 10,000 cycles a second, while systems have been developed up to 40,000 cycles per second over special land lines, giving excellent definition of a person's head and shoulders. This last figure seems about the limit that can be obtained with mechanical scanning devices as used at present, and with existing channels of transmission. It appears that future developments will be along the lines of non-mechanical means of scanning, such as the cathode ray oscillograph, together with the use of ultra-short wave transmitters which can be modulated at these extraordinarily high frequencies.

---

[1] This frequency is calculated on the assumption that, when transmitting the finest detail in the picture, alternate elements are black and white, so that two elements comprise one cycle.

Existing Systems.

At the present time nearly all the working systems of television employ mechanical means to scan the image, and so divide it into the elemental areas for transmission. The simplest of these—the Nipkow disc, is used by the Baird system in this country, and the Bell system in New York, while mirror and lens drums have been used by other experimenters.

Originally, the subject to be televised was flood-lighted by a very powerful illuminant, and a bright image thereof formed on the cathode of a photocell by a simple optical system. The Nipkow disc, with spirally arranged holes, was rotated before the cell cathode, so that at any instant the cell only received light through one small hole, while the whole cathode received the complete image once in each revolution of the disc. The heat and the glare associated with this floodlighting made the person being televised feel very uncomfortable. However, by using filters over the lamps and red-sensitive cells, thus working with only the infra-red or invisible radiation from the lamps, Baird reduced this inconvenience. This development led to "Noctovision" or "seeing in the dark," which was first demonstrated in 1927, and which was later applied to the problem of direction finding by infra-red light as an aid to combating fog difficulties at sea. (See also Chapter X for a description of this development.)

Nowadays, the subject being televised is scanned directly by a rapidly moving spot of light which shines through the holes of the rotating disc, and traverses the scene with a slender pencil of light.

As this pencil of light traces across the subject, light is reflected on to a number of photocells disposed round the subject, and the resulting photoelectric current is amplified in the usual manner. The number and size of the photocells is chosen to give a signal output which will be well above the noise level of the amplifier, and in some cases the total area of sensitive cathode exposed to the subject has been as much as 12 sq. ft.

Fig. 79 shows a television transmitter with a Nipkow scanning disc designed by Captain R. Wilson, which also shows the simple optical system employed. The light from an arc lamp is projected through the holes in the rotating scanning disc, and focussed by a projector lens and prism on to the person sitting before the photocells. There are 48 holes in the scanning disc, and the subject is thus scanned by 48 vertical lines. The disc is driven by a small motor, and a similar disc is mounted on a continuation of the motor shaft, so that the operator can observe the image being transmitted without being troubled with synchronization of the two discs. A straightforward six-stage valve amplifier, with simple compensation for high frequency loss, amplifies the current from one caesium-on-silver cell, and modulates the light from a special type of neon tube which is

FIG. 79. EXPERIMENTAL TELEVISION TRANSMITTER WITH MONITOR DISC

(*Capt R Wilson*)

viewed through the large lens seen on the right in the monitoring apparatus.

In the television studio, illustrated in Fig. 80, from which daily programmes are broadcast, four of the latest type of caesium-on-silver cells are mounted in a copper box in front of the sitter. The polarizing batteries and preliminary amplifier are mounted directly behind the cells, and the scanning light is projected through the aperture in the partition wall between the studio and the control room. This aperture is fitted with a plate-glass window to prevent the noise of the motor driving the scanning disc reaching the microphone in the studio. In the control room are located the amplifier and line correctors for both the vision and sound signals. These bring both the signal levels up to the correct value for the lines to the broadcasting transmitters some miles distant. Two receiving sets are installed with loud speaker and "Televisor" to enable the engineer to observe the transmission and correct the signal for any imperfections he may observe during the programme.

FIG 80 BAIRD TELEVISION STUDIO
(*Baird Television Co*)

The Bell Telephone Laboratories in New York City have a very interesting two-way television system operating between two booths over a distance of a mile and a half of special cable. Full details of this have already been published, together with the account of several very interesting amendments and improvements carried out during the last few months. A diagram, Fig. 81, is reproduced here of the Bell layout, in which the arrangement of the light source, scanning discs, and large photocells can be easily seen. The subjects desiring to communicate over this system sit in special booths, each facing two scanning discs, one for the transmitter and one for the receiver. In the sides of the booths are windows behind which are located large potassium photocells. The subject is scanned with a blue light to which the potassium cells show the greatest sensitivity, and the human eye the least. This arrangement is necessary for two reasons, firstly, because the image coming in from the other end of the line is reproduced on a neon tube giving a characteristic red light; and, secondly, because this tube has to be placed in such a position that the subject observing it might be dazzled by a bright scanning light if of an unsuitable colour. The size and definition of the received image give the illusion that the persons are conversing across a table about eight feet apart, and this effect is further enhanced by having the sound level from the loud speakers reproducing the conversation adjusted to the correct level for ordinary speech over this distance.

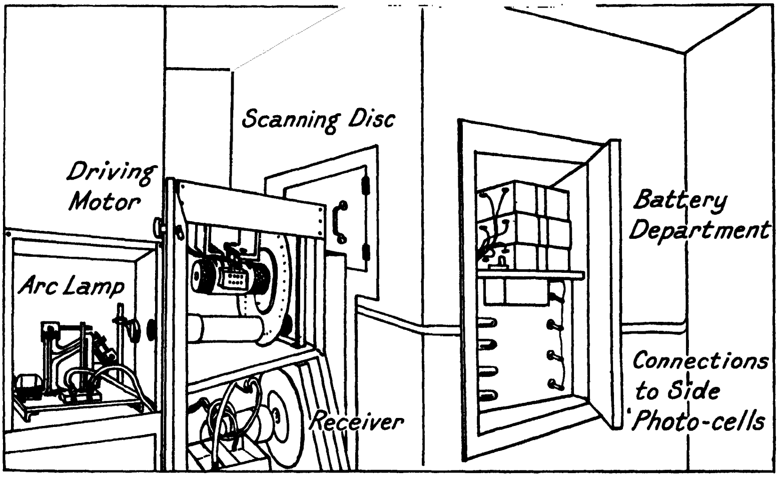


FIG. 81. BELL SYSTEM TELEVISION TRANSMITTER
(*Bell Technical Journal*)

This arrangement has given quite satisfactory results, but it was found very early in the service that the balance between the high lights of linen clothes and dark masculine complexions, was over emphasized by the blue light and blue sensitive cells, so that extremely contrasted images were obtained. This difficulty was overcome in an ingenious manner by using a deep purple light source in place of the arc lamp with blue filter, and by adding a group of red sensitive caesium-oxide cells in addition to the group of blue sensitive potassium cells.

An incandescent projector lamp with gelatine filter was substituted

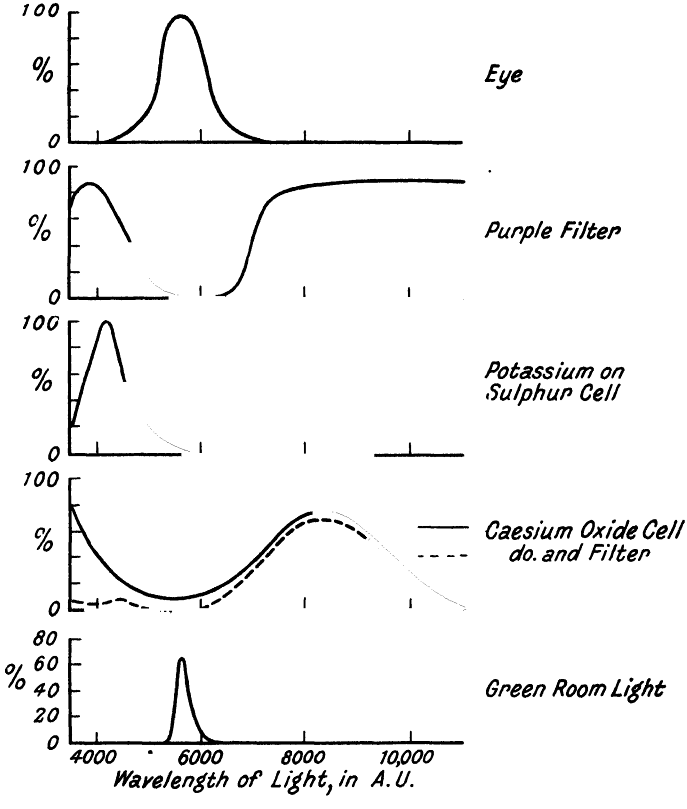


FIG. 82. COLOUR CHARACTERISTICS OF CELLS USED IN TELEVISION SYSTEM

(*Bell Technical Journal*)

for the light source, and thus, although the scanning light was still almost invisible to the observer's eye, the red component in the television signal was sufficient to relieve the complexion trouble.

The skilful handling of the characteristics of all the coloured lights, filters, and cells used in the new system, serves as an excellent illustration of the advantages which can be taken of the selective colour response of photoelectric cells with different cathodes. These characteristics are therefore reproduced here from Dr. Ives' paper in Fig. 82, and the five curves are practically self explanatory.

The colour sensitivity of the eye is given in the first curve, and the effect of the purple filter in the second, from which it is immediately seen that there is very little radiation visible to the eye in the scanning light. The next two curves illustrate the sensitivity of the separate groups of photocells which approximates roughly to the scanning light through the purple filter, while the last curve is for the small light used to give a general illumination of the television booth. Naturally, this light had to be chosen of such a colour that it did not affect the photocells in any way.

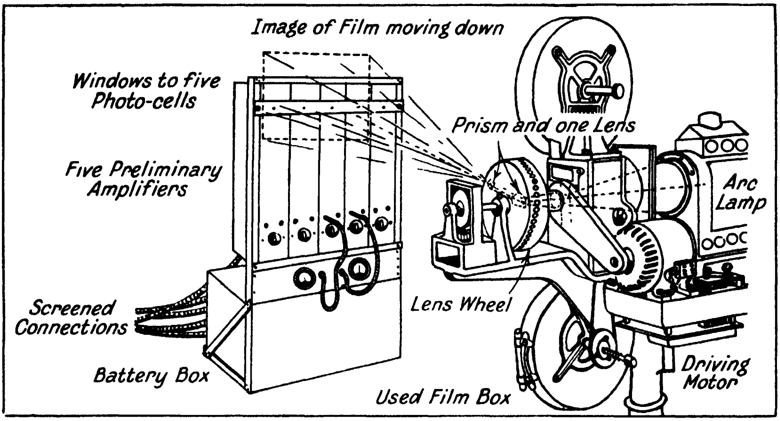


FIG. 83. GRAMOPHONE CO.'S FIVE-CHANNEL EXPERIMENTAL TRANSMITTER

(The Gramophone Co., Hayes)

Another ingenious television apparatus for transmitting cinema films has been demonstrated in this country by the Gramophone Co. (Fig. 83), in which images of the film formed by means of a lens mounted in a rotating drum are moved downwards across a screen containing five apertures, behind each of which is a photocell. The lens drum rotates once for each picture of the film as it stands stationary in the gate of the projector, and during that period each lens of the drum (of which there are 30) produces an image of the picture $\frac{1}{150}$ of the picture width to one side of the preceding image. The five small cell apertures being equally spaced across the width of the image on the screen, divide the picture into five sections horizontally, each of which is subdivided into 30 equal strips by this procession of the images. Each cell is thus made responsible for the transmission of a zone of the picture, and five sets of identical amplifiers, land lines, and receivers are used in the demonstration. Vacuum cells are also used since there is a very bright light source shining through the film on to the cells, and, therefore, the low efficiency of the cells becomes of less importance, compared with the improved frequency characteristics.

Assuming the cell windows to be square in shape, the frequency band required per channel would be 18,750 cycles per second. Hence, the total picture detail obtained corresponds to a single channel frequency of 93,750 cycles per second, or to a picture subdivision of 15,000 elements. Unfortunately, this frequency band has to be increased by 25 per cent, because the lens drum has, in addition to the 30 lens required for the scanning process, eight other blank spaces to cut off the picture from the cells during the period of movement of the film in the gate. This is the well-known intermittent movement of the cinema projector. The maximum frequency per channel is therefore increased to 23,440 cycles per second.

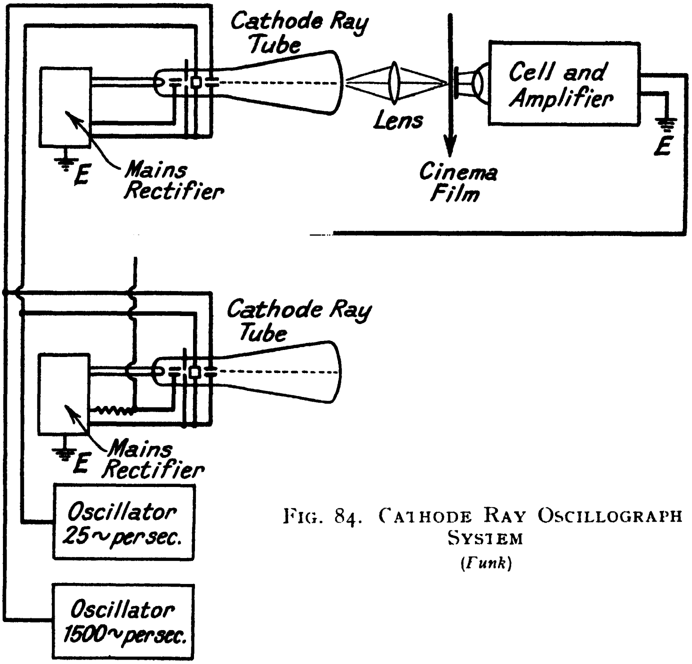


FIG. 84. CATHODE RAY OSCILLOGRAPH SYSTEM
(*Funk*)

Great care must be taken to avoid variation of density of the five sections due to slight differences in gain of the separate amplifiers.

A system of exploring by cathode ray oscillographs developed by M. Von Ardene, has been described recently, and offers great advantages over all mechanical methods of scanning.

In this arrangement identical Braun cathode ray tubes are used at both the transmitting and receiving ends of the system, which is used in the experimental form to transmit cinematograph films. By having identical tubes, synchronization of the scanning light spots is obtained very simply by parallel connections of the deflecting plates. (See Fig. 84.)

Synchronization of the receiving sets with the transmitter is one of the problems of television in which we have expressed no interest in these notes, but it will be obvious that this drive, free from mechanical inertia, for all the receivers is a very simple solution to the difficulty.

In both tubes the fluorescent spot scans a surface which is visible as a rectangle of light. In the transmitter, of course, the intensity of the light spot is kept constant and as bright as possible, and to this end a new fluorescent material has been produced which gives a very bright spot and a very low light inertia or persistence. Most fluorescent materials have a considerable light inertia, that is to say, they remain visible after the cathode rays have ceased to excite them. This would be a very objectionable effect in television, as it would blur the image.

The illuminated rectangle of the transmitter tube is focussed by a simple optical system on to the frame of the cinematograph film projector. The light passing through the film picture falls on the cathode of the photocell, so that for every position of the light spot there is a photoelectric current proportional to the density of the film at that point. The cell is connected to a two-stage amplifier of high gain, and apparently sufficient light on the cell is obtained to enable low coupling resistances (50,000 ohms) to be used. This considerably helps to maintain a good frequency characteristic, as has been explained in a previous chapter.

It has been found that if the deflecting plates which control the movement of the spot are excited with a sinusoidal variation in potential, the light field is not uniformly distributed and is weakest at the centre of the screen. For this reason, the well-known "flicking neon tube" circuit is used to give a "saw-toothed" wave form producing a uniform illumination over the whole surface. There are two of these oscillators deflecting the spot in two directions, one giving a frequency of 25 cycles per sec., and the other 1,500 cycles per sec. This corresponds to 60 lines scanning of the image, and as the frame is roughly square, 3,600 picture elements, or a frequency band of 100,000 cycles per sec. Actually, the image does not appear to be scanned in lines as is always so prominent a feature of mechanical scanning, and very good results are obtained, as shown in Fig. 85, which is from a photograph of the image picture of the film.

The main drawback to the system in its experimental stage is lack of detail due to the large diameter of the light spot which limits the effective picture subdivision to a few thousand. When this difficulty is overcome, the system should excel all mechanical methods.

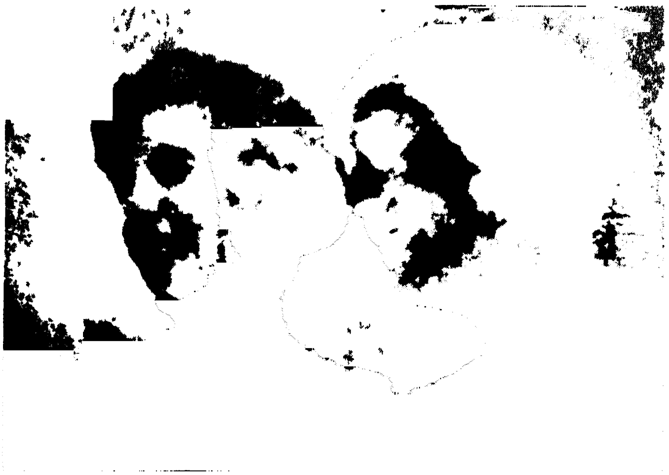


FIG 85 IMAGE OF CINEMA FILM TRANSMITTED BY CATHODE RAY SYSTEM

(Journal of Television Society)

Operation of Photocells.

In all these systems of scanning the image, where it is required to transmit along a given channel electric currents as replicas of the light changes on the cell, the function of the photocell is the same, and hence, the requirements of the cell are the same and can be considered collectively.

In the first chapter attention was called to the time lag of gas-filled cells at high magnification. Naturally, in this application where extremely high frequency light changes are to be translated by the cells, the study of this time lag is important. For accurate measurements on the response of photocells and amplifiers at supersonic frequencies, we can only quote the figures published by the Bell Telephone Laboratories in connection with the details of their system already referred to, as these are the only figures available from actual television research workers.

A Nipkow disc is employed in the Bell system, with 72 holes and with a picture repetition of 18 per sec., which requires a frequency band of 40,000 cycles. The photocells used are of the gas-filled potas. um type, and in consequence of the gas-filling there is a loss in response and a phase shift at the higher frequency component of the television signal. Altogether, in each transmitter, there are twelve large cells connected in three groups. Each group is connected in parallel to the input resistance of a two-stage preliminary amplifier; mounted in the same box as the cells. The loss at high frequencies, due to the gas-filling and due to the capacity of the cells and connections to earth, is equalized in the intervalve coupling of the preliminary amplifier so as to be within 1 decibel or 10 per cent up to 40,000 cycles per sec. We reproduce this published frequency characteristic, Fig. 86, for the loss in response of these large cells, for a single cell, a group of cells, and the equalized output from the amplifier.

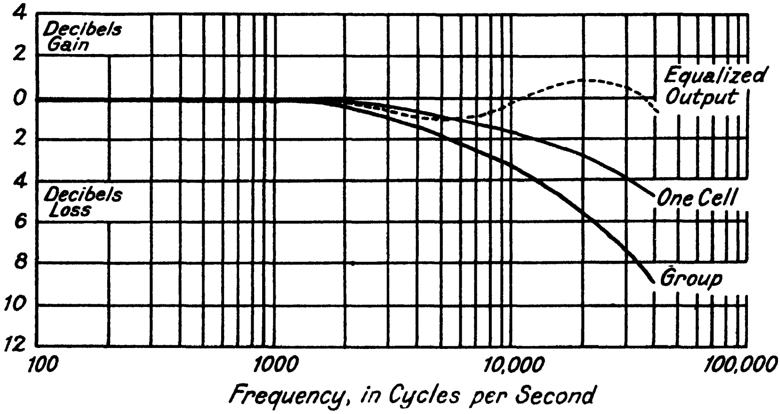
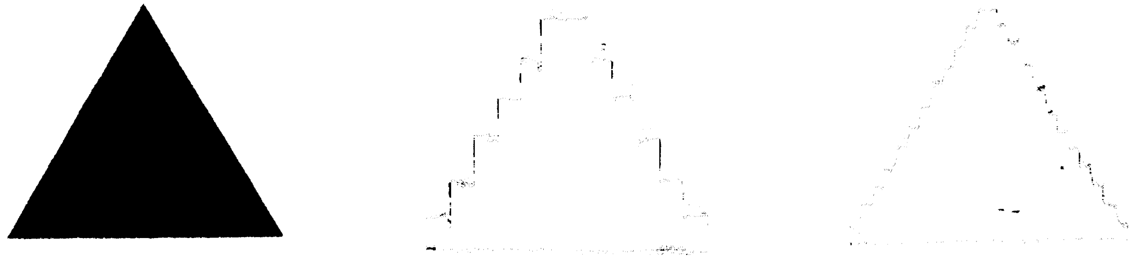


FIG. 86. FREQUENCY CHARACTERISTIC OF PHOTOCELL AMPLIFIER
(*Bell Technical Journal*)

In most cases of direct scanning of living objects, the amount of light available even with the largest areas of cathode, is not sufficient to give reasonable results with vacuum cells. Unfortunately it is not possible to increase the output by increasing the number of s ages of amplification owing to the limit imposed by the Schrot and similar effects in the amplifiers which produce a background of "mush." Hence, gas-filled cells have to be used and the amplifiers



Original Pattern

Scanned by 12 Strips

Scanned by 24 Strips

Fig. 87*a* Scanning Distortion

compensated. This has been done satisfactorily by quite simple circuits both as regards phase angle and frequency characteristic.

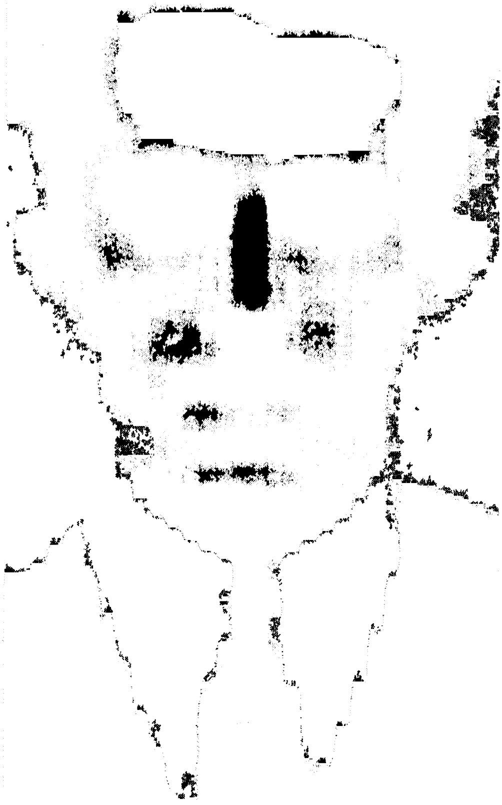


FIG 87*b* HUMAN FACE SCANNED BY 30 STRIPS

Of course, the output from the photocells can be increased by increasing the brightness of the light source, or by having larger holes in the scanning discs. But this latter suggestion decreases the definition, however good the rest of the system. This is because the finite size of the point of light scanning the subject has an important control on the detail of the picture, as it reduces the number of elements into which the latter is subdivided. This effect is explained most quickly by an inspection of the diagram, Fig. 87*a*, where the definition obtained with a simple geometric pattern with various sizes of holes is shown clearly. As the light spot passes in its scanning of the picture from an "all-black" portion to an "all-white," the photoelectric current changes from the minimum to the maximum value gradually and rectilinearly, so that the sharpness of the division between black and white in the receiver is blurred. This problem has been analysed in great detail by Dr. Fritz Schroter for many geometric patterns.[1] It will be obvious that the more elaborate the detail to be transmitted, the more important this distortion becomes. The effect can be reduced only by reducing the size of the light spot or increasing the scanning speed. When these simple patterns are replaced by complicated images such as the human face shown in

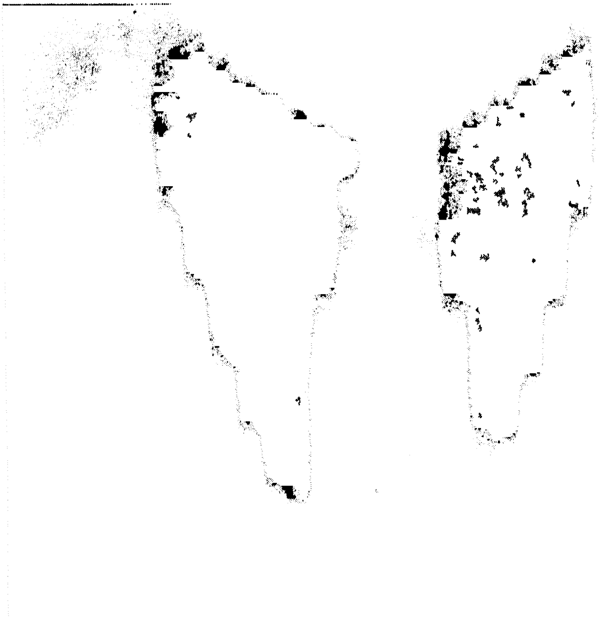


FIG 87*c*. ENLARGEMENT OF 87*b*

---

[1] See *Television*, April, 1930 Translation from *Elektricher Nachrichtentechnik*, Berlin, 1929

Fig. 87*b*, this limitation of the definition becomes a serious point. This illustration has been specially prepared to show the manner in which the picture is composed in a 30-line scanning system. An enlargement of a small portion of the chin and necktie is also given to emphasize this point.

As mentioned above, the photoelectric cell and its preliminary amplifier in a television system are followed by amplifiers of as high a gain as possible. It is therefore necessary to take the most elaborate precautions with the metal screening.

In the next diagram, Fig. 88, is given the circuit associated with the transmitter illustrated in Fig. 80. It will be noticed that the amplifier is divided into three sections, the *A* or "1st vision" amplifier of five stages of corrected resistance-capacity coupling, a phase switch, and a change-over to either of two output amplifiers.

The first of these is for local demonstrations on receivers in the same building, and the second is for connection to the land lines to the broadcasting transmitter. The phase shift switch is necessary because, occasionally, due to changes in connections to external circuits, the reception over the radio comes with a negative image, and has to be reversed to give a correct positive. The cell working into a high resistance circuit

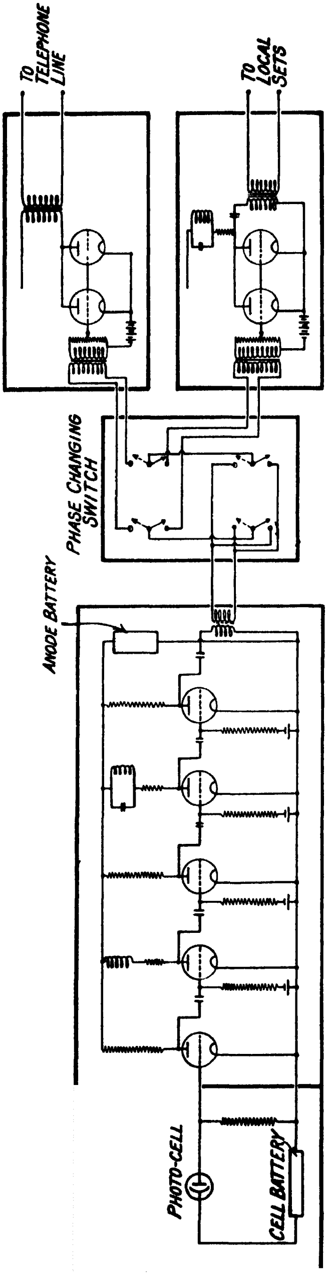


Fig. 88. Complete Circuit of Television Transmitter
(*Television*)

will render the first amplifier extremely sensitive to radio and static interference, while the first valve will have to be carefully protected against microphonic disturbances. It is usual to enclose cell, valves, and batteries in a copper box, felt-lined, with copper gauze over the cell windows and to use screened connecting leads.

Colour Television.

Several suggestions have been put forward by various experimenters for securing natural colour television, and some of these suggestions have actually been tried out, although little information is available regarding the results.

Monochromatic television has presented enough difficulties, as explained in these brief notes of working systems, and the art is hardly ready for the added complications of more channels per transmission for either two or three coloured images.

Baird demonstrated in 1928, the possibilities of three-colour television over a single channel by employing a scanning disc with three spirals of holes covered with red, green, and blue filters, and the standard spotlight transmitter, presumably with potassium cells. In the receiver the image was reproduced on gas discharge tubes filled with neon, argon, and helium respectively, a commutator on the receiver disc switching the incoming television signal to the corresponding colour tube. It was found unnecessary to run the disc at three times the speed as might have been expected, but the frequency band was of course triple that required for monochromatic work.

In 1929, Dr. Ives described an attempt at colour television over a two-way system, somewhat similar to the Bell System in New York. The photocells arranged round the subject were connected into three groups with separate amplifiers and transmission lines, one for each colour. As presumably potassium-on-sulphur cells were used, it was found necessary to use twenty-four cells, two with blue filters, eight with green, and fourteen with red filters to approximate to a three-colour process with correct balance. In the receiver the lights from three gas discharge tubes were superimposed to form one image.

No descriptions are available of systems using the colour sensitivity of different cathodes to supply the subdivision into the three primary colours. The development of the Bell System already described, designed to overcome the lack of response of their original system to red complexions, is a step in this direction, but with photocell analysis the response to colour will always be very selective and, hence, correct natural colouring will be difficult to obtain. An approximation by a two-colour process may, however, offer a solution by producing a tinted image, but the sharp selectivity of the cells will mitigate against natural results. In addition, the sensitivity of the various cathodes varies enormously, so it seems that before much success attends these experiments, photocells with panchromatic characteristics will be required. These same limitations were felt in the early days of photography from exactly the same cause, but these difficulties all vanished when the panchromatic plate was introduced. So presumably will the television difficulties vanish when a panchromatic cell is produced.

It is difficult to attempt to predict the future of Television, but observations lead to the conclusion that developments will lie along two distinct lines, i.e. two-way transmission as an adjunct to the telephone, and a new projection method for the cinema. Home television will only, as far as can be seen at present, remain little more than a shadowgraph, because the receiving apparatus must of necessity be cheap and simple, whereas the apparatus installed by the telephone and cinema corporations can at once be complicated and costly, and will always be under the supervision of trained engineers. There is certainly a potential field for development of television in the cinema industry, as it is the industry which has the necessary liquid capital for the costly experimental work.

Under the cinema control, plays and films will perhaps be transmitted from a central studio to a chain of cinemas throughout the country where the scenes will be viewed on large screens. No doubt the work of these elaborate systems may possibly produce the clue to simpler receivers capable of giving real entertainment of a standard comparable with the home cinema. However, it is a moot point whether the appeal of television will remain in the home after the initial novelty has passed. One thing is certain—that whatever developments take place the photoelectric cell will be the essential link in the transmissions.

The photoelectric cell is, of course, not a component of the receiving set, so that it is not intended to give here any account of such apparatus or its method of operation. For this information the reader is referred to the excellent description of such equipment which has from time to time appeared in *Television*, and to the references appended hereto.

CHAPTER IX

SCIENTIFIC INSTRUMENTS

We have seen that the alkali metal photocell is the most satisfactory device for producing electric currents from light, and that in the case of the vacuum cell, a strict proportionality exists between the two physical quantities. Also, when suitable means of detection are available, the most feeble illuminations can be accurately measured and recorded by their use. It is little wonder, therefore, that the photocell forms an essential part of many interesting and useful scientific instruments. In fact, the earlier types of cells were developed purely for laboratory use, and only came into the industrial world after their value and convenience had been appreciated by the physicist. Lack of space here forbids all but the briefest outline of one or two representative examples of apparatus which has proved extremely useful to the physicist and the engineer.

The Microphotometer.

This instrument has performed useful service in the realm of astrophysics, inasmuch as a good deal of information concerning interstellar space outside our own planetary system has been acquired with its assistance. Fundamentally, it enables chart records of the luminosity of stellar images to be made after these have been photographed directly. The Cambridge Instrument Co. have recently developed an instrument which is a modification of the Dobson-Skinner microphotometer, and which enables graphical records to be made of the contours of Solar Fraunhofer lines, measurements of spectrum lines both along and at right angles to the direction of dispersion, resolution of Zeeman patterns and multiple lines and determination of lines of equal brightness in nebulae and the solar corona, all of which are interesting and useful to the astronomer. The optical essentials of the instrument are shown in Fig. 89. The filament of the standard lamp L is focussed on the optical wedges W, between which a V-shaped diaphragm limits the effective length of filament and, therefore, the effective length of the slit. By means of the lens O_1, a small image of the lamp filament is formed on the portion of the photographic plate to be measured. An enlarged image of the part of the plate illuminated is formed on the slit S by the lens system O_2. A thin collodion film f, serves to send a portion of the light to an eyepiece E for the purpose of observation and adjustment of the field of view. The slit is adjustable up to the width of the magnified image of the filament formed upon it, and this adjustment determines the width of the plate area under measurement. The lens system gives a magnification of about twleve, so that records are not vitiated by slight inaccuracies in the edges of the slit. The light passes through the slit on to the photocell, which is an Osram type CMG 7, and this cell is connected through a second cell R_1, which serves as a variable high resistance to the Lindemann Electrometer (Fig. 90), which is fitted with needle and pointer specially designed for projection. If the two cells have similar cathodes, a compensation can be obtained for small variations in the lamp *L*, *R* being

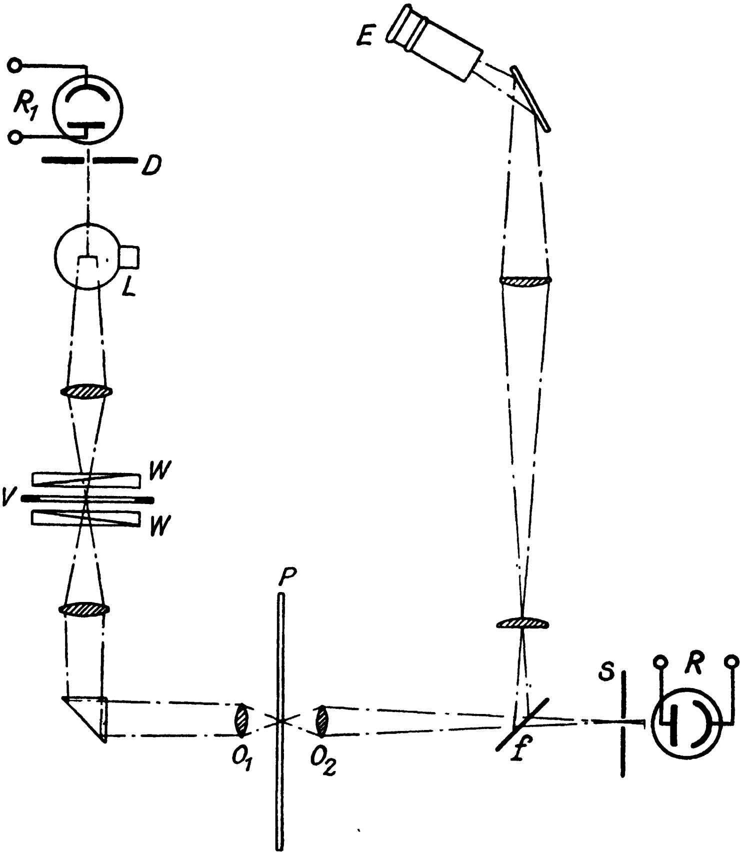


FIG. 89. OPTICAL SYSTEM OF MICROPHOTOMETER
(*Cambridge Instrument Co.*)

illuminated through an adjustable diaphragm *D*, which also serves as a simple means of altering the resistance of *R*, and so changing the damping and sensitivity of the electrometer. To secure as great a constancy of illumination as possible, the lamp *L* is operated from a large battery. An image of the electrometer needle is projected by means of light from the lamp *I* (Fig. 90) and the microscope *M* on to the recording drum *G*. Fig. 91 shows a general view of the apparatus. Normally, the slit and filament are at right angles to the direction of travel of the plate carrier. By changing the lens system and the aperture *S*, the size and shape of the slit can be altered. The plate carrier *C* can move in two directions at right angles, so that the centre of the region to be measured can be at any part of a plate 12 in. sq. A micrometer screw is provided for fine adjustment of the plate carrier, and a low-power telescope placed at one side of the wedges *W* enables the image of the filament, together with a portion of the surrounding field, to be viewed directly. The plate is held by clamps, and can be adjusted in position so that its plane is perpendicular to the optic axis of the lens system O_1O_2. When in operation, the plate moves slowly at a uniform speed in a fixed direction, and is connected by gearing to the recording drum carrying the sensitive paper on which the electrometer needle deflection is recorded. Change-over pulleys on the belt drive coupling to the motor permit the rate of travel of the plate to be varied. Friction drive of the recording drum avoids backlash in gearing. The cylindrical lens *l* is engraved with vertical lines spaced one millimeter apart, so that the chart is crossed by a series of white lines on a black ground, and these can be used as a scale for measuring the recorded deflections. The shutter *T*, controlled by electrical contacts in the driving gear, cuts off light from the projector at each millimeter travel of the plate, so that another white line at right angles to the previous set is formed, enabling the exact position of the point on the plate to be determined. On completing one revolution of the drum, the paper clip operates a

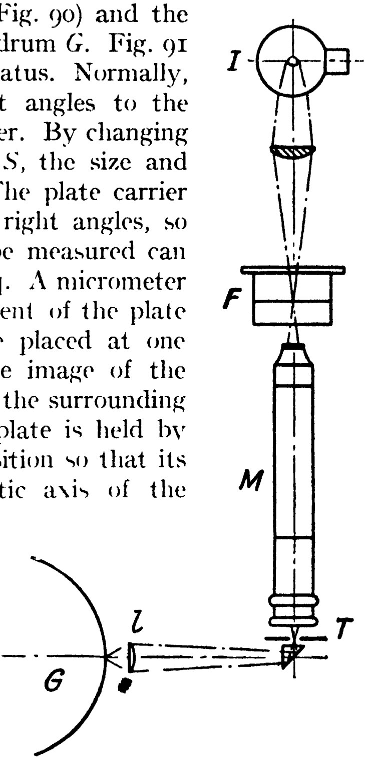


FIG. 90. RECORDING SYSTEM OF MICROPHOTOMETER
(*Cambridge Instrument Co.*)

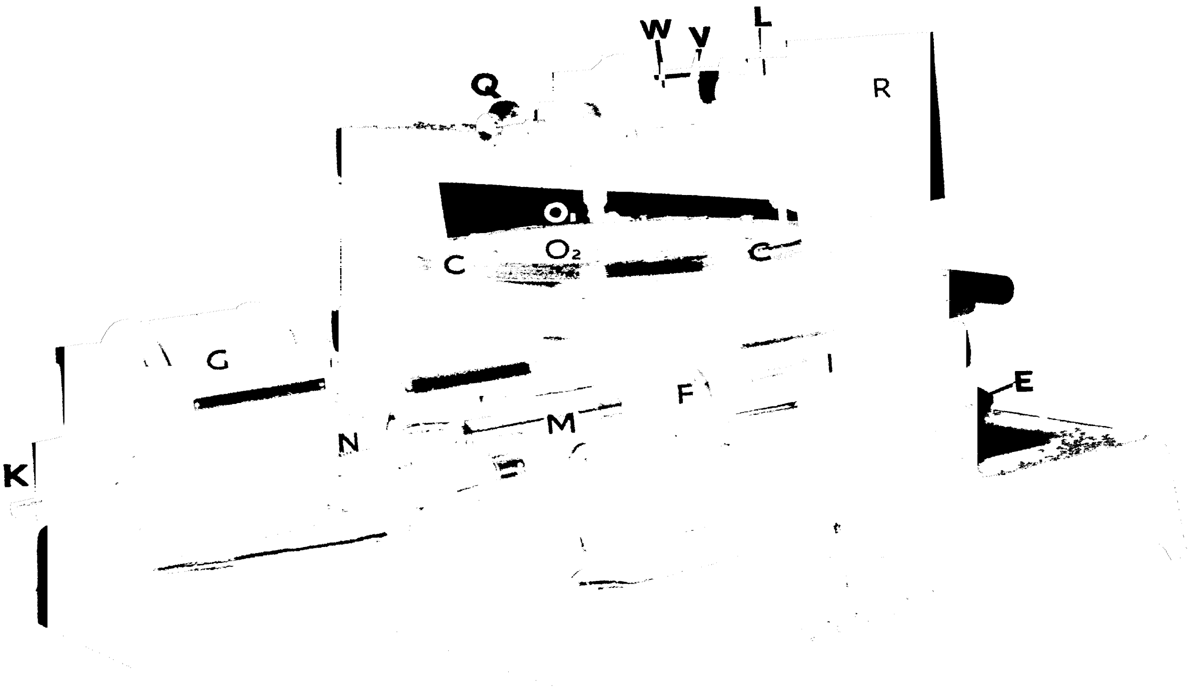


FIG 91. GENERAL VIEW OF RECORDING MICROPHOTOMETER
(Royal Astronomical Society)

switch which stops the rotation. One of the wedges is movable by a micrometer screw *Q*, so that the instrument can be used for visual observations, and the other wedge is movable in fixed steps increasing in density of 0·5 at each step. In each, the gradient of the two wedges being opposite in direction, a uniform density stratum of adjustable magnitude can be interposed in the beam from the lamp. A third wedge with stepped degrees of density can be used alternatively. The use of this wedge permits of the instrument being used for deflections which would normally fall off the scale. Full-scale deflections can be obtained for density changes of 0·5 (minimum) to 3·0 (maximum), and the plate normally travels at 6 mm. per minute, though provision is made for more rapid speeds for the purpose of setting. The instrument is very sensitive at low densities, and to a degree dependent on the intensity of illumination. Fig. 92 shows a typical chart record, in this case of contours of the *D* sodium lines.

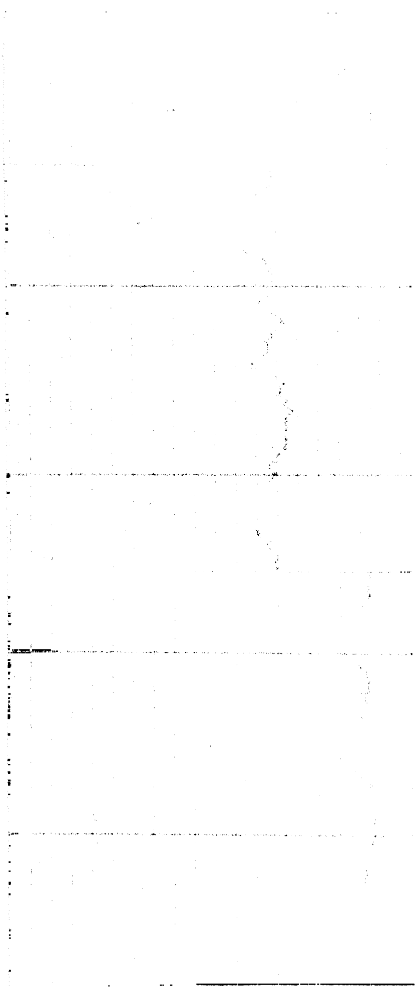


FIG. 92. RECORDER CHART
(Royal Astronomical Society)

Photographic Density Meter.

This instrument is constructed by Messrs. W. Watson & Sons, and has been used by the British Photographic Research Association for the measurement of the densities of photographic plates. Fig. 93 shows a sectional end elevation of the most recent form of the apparatus, and Fig. 94 a diagrammatic sketch of the optical system, which is the same as that used in an earlier form of the same instrument. A special photocell having two windows to admit light from two directions on to the cathode was designed for this instrument, and its adoption enables a very simple optical system to be used. The whole assembly really constitutes a density comparer, the

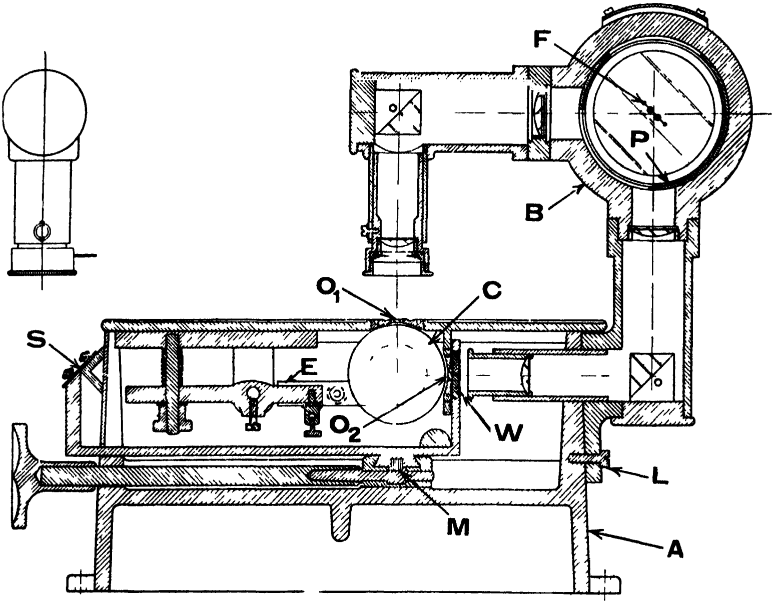


FIG. 93 END SECTION OF PHOTOGRAPHIC DENSITY METER
(W. Watson & Sons)

light entering the cell through the unknown density being compared with that passing through a standard optical wedge, the density of each point of which is known. The cell is placed with each window in contact with an opal diffuser, so that practically all the light passing through the negative or the wedge will enter the cell. The filament of the light source, which is a 24-watt lamp, is equally inclined to the direction of projection of both light beams. Light is concentrated by the optical system L_1L_2 (Fig. 94) on to one diffuser O_1, and similarly the second beam is directed on to O_2 by the lens system $L^1{}_1L^1{}_2$. A uniformly illuminated image of the lens aperture L_1 is formed on O_1 by a suitable selection of the optical constants.

The negative is placed in contact with O_1, and the optical wedge is moved across O_2 in a direction perpendicular to the plane of the paper. A shutter S is placed round the lamp so that when it is rotated, the cell is illuminated by each beam alternately. This shutter consists of a metal tube from which a sector rather larger than a quadrant has been cut. A second and similar tube slides over the first and is adjustable, so that the two give an exact quadrant. Zero balance is obtained by a diaphragm adjustment over L_2 or by rotating the lamp in its holder. The Ilford wedge W has a uniform density gradation, and the density at the opal O_2 can be read off on the vernier scale provided on the front of the machine. The electrical circuit is but a slight modification of that shown in Fig. 10, and calls for no special comment. Since equal distances along the optical wedge correspond to equal increments in density, the density values can be easily plotted against the logarithm of the corresponding exposure by means of a suitable arrangement of levers attached to the wedge carrier. It can be shown by calibration with negatives of known density difference, that a linear relation between density and wedge reading exists, and that this is independent of the type of negative under consideration. As the sensitivity, according to the relationship stated above, falls off rapidly as the density of the negative increases, it is essential to use a shunted galvanometer whose maximum sensitivity is much greater than is necessary for low densities. The instrument can be used in daylight

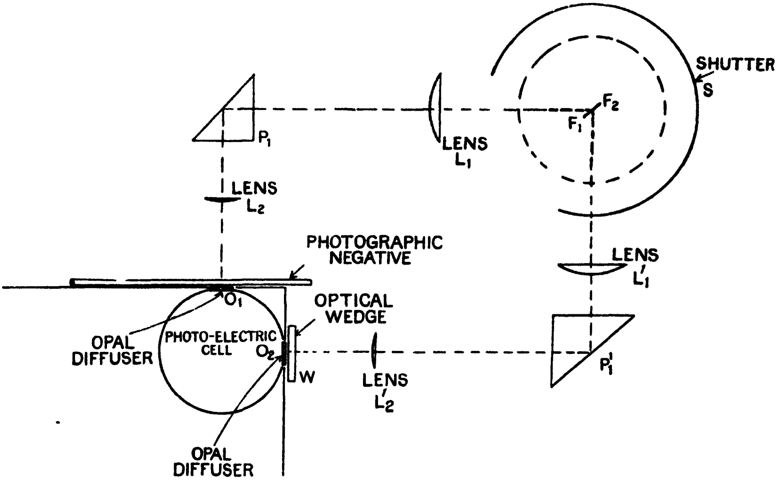


FIG. 94. OPTICAL SYSTEM OF PHOTOGRAPHIC DENSITY METER
(*By Courtesy of Dr. Toy*)

or artificial light, provided direct radiation does not fall on the negative. With the assistance of this instrument, a single observer can, in a day, make a large number of tests on opacities varying from 1 to 10,000, plot the curves, and tabulate the results.

Measurement of Ultra-violet Rays.

The lower limit of visibility in the spectrum for most individuals is about 3,900 A.U. Below this limit exist the invisible radiations known as the ultra-violet, which are exceedingly active chemically—in consequence of which the spectral range can be easily mapped by photography—and which possess therapeutic properties. There is some difference of opinion as to which portion of the ultra-violet spectrum is definitely therapeutic, and it is not our intention to discuss the question here. The photoelectric means adopted for measuring dosage of ultra-violet radiation in medical treatment is, however, of definite interest. Either sodium (4,000–3,000 A.U.), cadmium (below 3,000 A.U.), or uranium, are suitable as photoelectric cathodes according to the portion of the U.V. spectrum it is desired to observe. Since glass absorbs radiations of this region, it is necessary to construct the photocell to be employed, with a quartz window to enable the ultra-violet rays to reach the cathode. The use of a complete quartz bulb is a costly and unnecessary elaboration. The thin quartz window is conveniently attached to the glass bulb by means of sealing wax. During manufacture, the joint must obviously be kept cool, and in order to prevent the alkali metal condensing on and obscuring the window while being distilled into the bulb, a small glass disc is previously introduced into the bulb to cover the window during this process of manufacture. It must subsequently be shaken down into the well of the bulb. Obviously, it must not be allowed to lie in contact with both electrodes at the same time as it is covered on one side with a metallic film. Fig. 95 shows diagrammatically the apparatus designed by Messrs. Watson & Sons (Electromedical), Ltd., for measuring ultra-violet ray dosage. The cathode of the photocell is connected to the gold leaf of the electroscope, and the anode to the case. The cathode is negatively charged from a battery of small cells or from direct current mains, if available, with a protective resistance of 0·5 megohm in circuit. The instrument is designed primarily to measure radiation between 2,000 and 3,000 A.U. Radiation of this nature reaching the photocell causes the electroscope to charge up and the leaves to diverge until the movable one touches a small carbon earthing rod, when the charge escapes and the leaves are restored to their original position, and unless the source of U.V.

radiation is removed, the cycle of events is repeated. This cycle constitutes a "beat," and the time occupied in making one "beat" is a function of the strength of the source of ultra-violet radiation. For two sources of radiation at the same distance, the strengths are inversely proportional to the time of one beat. A shield with a variable aperture is placed between the source of the radiation and the photocell to limit the beam of rays reaching the cathode. If

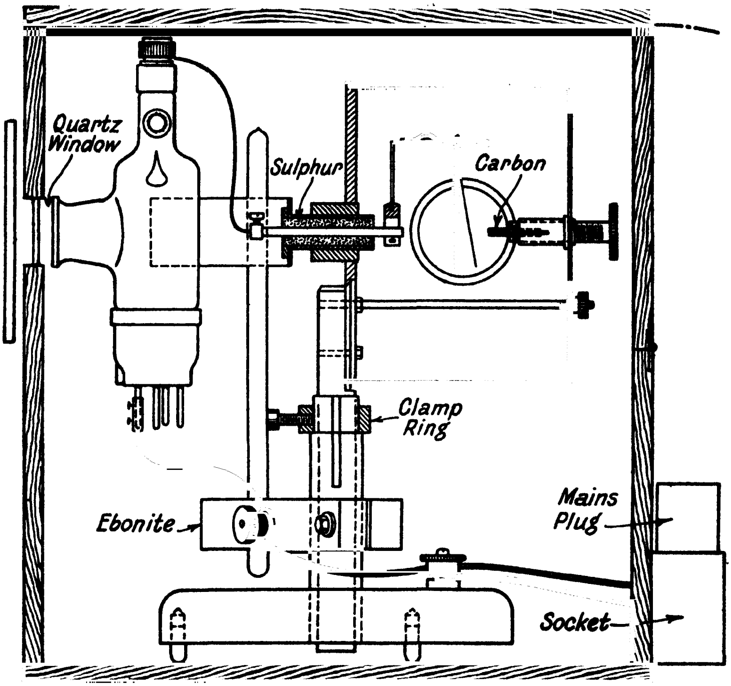


FIG. 95. ULTRA-VIOLET RAY DOSAGE METER
(*Watson & Sons (Electromedical), Ltd.*)

d = diameter of this aperture in inches.

D = distance of source of radiation.

T = period of one beat.

P = strength of the source of radiation,

then $P = \frac{kD^2}{Td^2}$

k being a constant of the cell and electroscope combination.

If P is expressed in arbitrary units, k can be made unity. When using the instrument, the time of, say, ten beats is observed, and T thence deduced as an average. The most satisfactory results are obtained if T is about 10 sec. During the process of manufacture of a photocell, some of the alkali metal becomes deposited on the anode and, in consequence, the cell will give a slight photoelectric response if the polarity of the applied potential is reversed. This is a case where the instrument will function—though much more slowly—if the battery leads become reversed. A trial will at once indicate the correct way of connecting it up. It is important that this type of instrument should be kept warm and dry to avoid the possibility of insulation troubles.

Photometry of Ultra-violet Rays.

The measurement of the distribution of ultra-violet radiation has been recently undertaken by Mr. Jeffree of the Clarendon Laboratory, with the aid of the photocell and spectrometer. The instrument used consists of an aluminium casing containing the photocell and optical elements. The radiation to be examined passes through a quartz diffusing screen and enters the slit of the spectrometer. By means of a 60° quartz prism and concave mirror, a spectrum is formed, and by the addition of a suitable condensing lens all radiations reach the photocell. Metal shutters, which carry a scale of wave lengths, are arranged so that any required region of the spectrum may be cut off. To compensate for selective response of the photocell, a screen consisting of a metal plate suitably shaped and prepared from data obtained from a calibrated cell is used to cut off a portion of the spectrum. Measurements are made with a Lindemann electrometer and reading microscope.

Photometry of Light Sources.

The measurement and comparison of the light output of artificial sources of illumination is a problem which especially interests lighting engineers, designers, and service departments of all municipal and company electricity supply undertakings. This is particularly so in the case of vacuum and gas-filled electric lamps, where running costs, life, and illuminating power are factors demanding some form of standardization. For many years it has been the usual practice to measure the luminous output of a lamp by comparison with the output of a standard source of known characteristics, using some form of bench photometer in which the lamp under test is adjusted in position relative to the standard source until they both produce equality of illumination on two adjacent surfaces. The observer's eye decides when this condition of equality of illumination has been attained, and upon this decision depends the accuracy of the subsequent calculations. The probable errors of such measurements are usually 2 per cent to 4 per cent, an accuracy which is frequently good enough for all practical purposes: but with recent improvements in lamp manufacture, higher accuracy, together with rapidity of measurement, becomes almost imperative. A cursory perusal of Chapter I may have led the reader to suppose that the photocell provides a means of making such measurements easily and with great accuracy. Unfortunately, there are several limitations, and measurements of high accuracy may necessitate considerable elaboration of apparatus. Before briefly outlining the use which has been made of the photocell for lamp photometry, it may not be out of place to refer to the instrument shown in Fig. 96, which can be used for making measurements of the horizontal candle-power of lamps, for tracing polar distribution curves, and light absorption of glass fittings. The instrument consists of two portions, the left-hand compartment contains the electrometer, microscope, and graduated scale, while the other section houses the 6 megohm potentiometer, which permits of voltage adjustment on the cell and electrometer plates. The adjustments are made by small control dials mounted on an insulated panel and provide for convenient variation of the

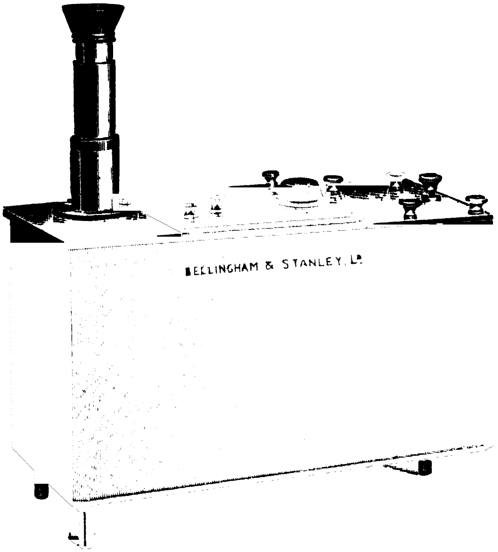


FIG. 96 PORTABLE PHOTOELECTRIC PHOTOMETER
(*Bellingham & Stanley, Ltd*)

sensitivity. If the greatest sensitivity is desired, the control dial varying the cell voltage is set approximately central, and the negative end of the H.T. battery adjusted so that total voltage is slightly in excess of the glow potential of the cell. The electrometer potential is then raised by the other control dial to give a convenient scale reading in the microscope. The cell control is then gradually adjusted while the electrometer reading is observed. As the cell voltage is raised, the pointer will approach the zero end of the scale, and just at the glow potential will return to the higher end of the scale. The control dial should then be adjusted until the lowest stable reading is obtained, and the voltage on the electrometer plates varied until the pointer reads as nearly as possible zero. The apparatus will then be in its most sensitive state. A high resistance across the electrometer needle and the positive end of the potentiometer enables the former to discharge and return to its zero position. The right-hand compartment contains the lamp battery and adjusting resistance.

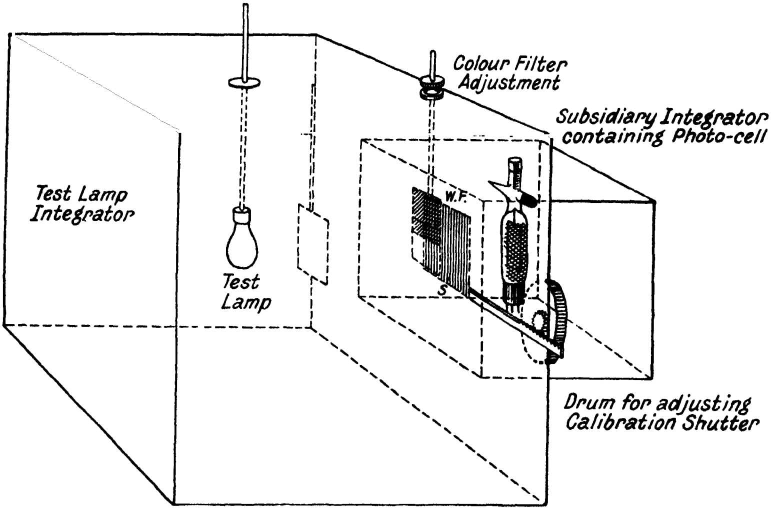

Colour Filter Adjustment
Subsidiary Integrator containing Photo-cell
Test Lamp Integrator
W.F.
Test Lamp
S
Drum for adjusting Calibration Shutter

FIG. 97. PHOTOELECTRIC PHOTOMETER

Photoelectric photometers for commercial rating tests on lamps have now been developed, and their use enables speed and accuracy exceeding that obtainable by visual methods to be attained. A brief outline only is given here, and for further details and the history of the development of the apparatus, the reader is referred to the original papers.[1] Fig. 97 shows diagrammatically the arrangement of a suitable photometer. The cube or integrator in which the lamp under test is placed consists of an internally whitened chamber fitted with a screen which prevents direct light passing from the lamps through an aperture on to the photocell. The light which passes is therefore a measure of the mean spherical candle-power of the lamp under test, and is independent of the position of the lamp inside the cube. Adjustment of the light which enters the subsidiary integrator containing the photocell, is provided for by the calibrated shutter *S*, and there is also an adjustable colour filter *K*. In this photometer the vacuum type KMV photocell is used together with valve amplification, employing the circuit shown in Fig. 98. It will be noted that two valves are connected in a bridge

---

[1] *G.E.C. Journal*, August, 1932.

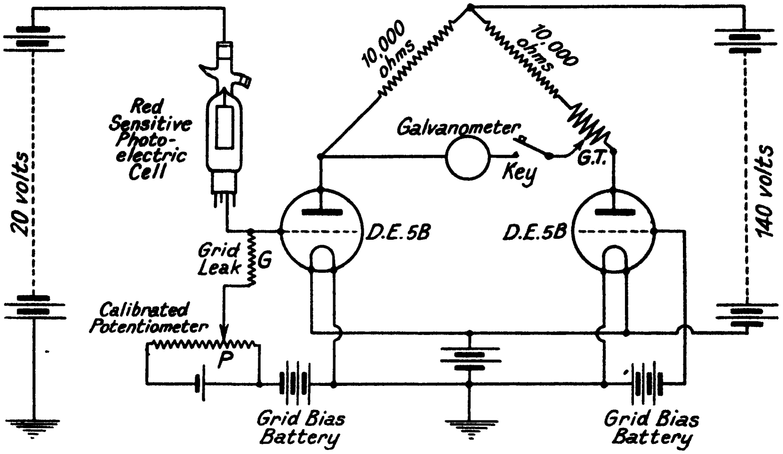


FIG. 98. BRIDGE CIRCUIT FOR PHOTOMETRIC MEASUREMENTS
(*General Electric Co., Ltd.*)

circuit in order to minimize the disturbing effect of small changes in H.T. and filament voltage. When the cell is dark, the grid bias is adjusted so that no deflection is shown on the galvanometer. Potentiometer control of the grid bias enables the null deflection to be maintained when light is incident on the cell. It is thus possible to calibrate the grid bias voltage in terms of the lamp lumens over a considerable range. D.E.5.B valves specially aged and selected are found to be most suitable and require a minimum of zero adjustment. The range over which the potentiometer *P* can be made to read in lumens is variable by altering the value of grid leak *G*, which has values 40, 50, 55, and 60 megohms, and also by an aluminium shutter *S*, moving at right angles to the colour filter. This can be moved without altering the ratio of filtered to unfiltered light. The colour sensitivity of the instrument is checked by using two lamps operated so that their light output is similar but at temperatures 2,350K and 2,700K respectively, these temperatures representing the range of the instrument. The filter is then adjusted so the two lamps balance at their nominal value on the potentiometer. With the cell dark, the potentiometer is set to zero and the galvanometer balanced. A standard lamp is then put in the integrator, the potentiometer set to the known lumen value, and the galvanometer balanced by the shutter *S*. The instrument is then in adjustment and is capable of reading lumen values over the range 80–1,500. It is essential that there shall be very efficient screening of the apparatus, or else trouble will be experienced from external parasitic disturbances. Precautions have also to be taken to secure high insulation and freedom from small voltage changes. For this reason, all sources of electrical supply are screened accumulators. This photometer is simple to operate, and with one operator is capable of routine work dealing with about 150 lamps per hour. Closely allied to the problem of determining the lumen output is the question of colour temperature measurement, which is of considerable interest to the electric lamp manufacturer.

Colour Changes.

The fact that the sensitivity of a photocell is not uniform for light of different colours, and varies with the radiation from different parts of the spectrum, naturally suggests that this property could be employed to detect changes in the colour of the light reaching the cell, and that photocells could be used for colour-matching devices. It will have been gathered from Chapter I that the potassium cathode has a maximum sensitivity to blue light and is practically insensitive to red, whereas the converse is true of the CM type cell, so that a combination of two such cells would enable the discrimination of blue light from red light to be made quite easily. Such obvious and extreme colour differences, however, are generally detectable by other methods, and colour problems are not usually as simple as this. In practice, the photocell is frequently required to make discrimination of small colour differences as good as, if not better than, that made by the eye, and the problem is often one which has successfully resisted attack by all other methods. Consequently, a complete solution of the problem may entail elaboration which renders it impracticable in application.

Experience shows that colour problems usually resolve themselves into three groups.

(1) Standardization of semi-transparent solutions.

(2) Comparison of radiation from emitting sources.
(3) Matching of coloured surfaces.

The first group generally permit of investigation by transmitted light, the comparison usually being between two liquids of a similar nature, or between two samples of the same liquid, one of which may be regarded as a standard, it being required to operate some indicator when the second liquid differs in depth of colour from the first. This problem occurs frequently in industrial applications where it is required to cut off the supply of one ingredient automatically as soon as equality of colour as compared with a standard has been attained, in the process of mixing coloured solutions.

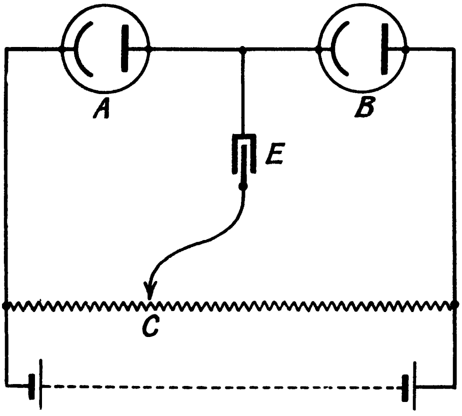


FIG 99 SCHEMATIC DIAGRAM OF COLOUR MATCHING BY TWO CELLS

Actually, in such cases, the problem becomes one of securing equal intensities of transmitted light, and for this purpose the two-cell circuit, shown in Fig. 99, can be conveniently employed. Vacuum cells should be used, and selected to have cathodes which are most sensitive to the radiation absorbed by the solution. Preliminary experiments are generally necessary to decide on the type of cell to be used, as visual judgment is invariably too unreliable. It must be remembered that the photocell is very sensitive to intensity changes of light, whereas the eye is easily deceived by a relatively large difference in illumination. On the other hand, the eye is much more sensitive than the photocell to colour change, so that it is always desirable, if possible, to make the solution of the problem depend on equality of intensity rather than identity of colour, if photo-electric apparatus is to be employed.

Problems under heading (2) arise in connection with pyrometry and colour temperature of incandescent bodies, and have been attacked by the use of bridge circuits using two photocells with different cathodes. The primary emission of a photocell to radiation of a definite wave length is proportional to the intensity of the light of that wave length, but the factor of proportionality differs with the wave length and the type of cell. If two cells for which this factor is the same are exposed to a source of light, and the currents through them are made equal by means of a shutter over one cell, then the currents will continue to be equal to one another when the light source is changed for another of different intensity or colour. If, however, the factor is different for the two cells, the currents will

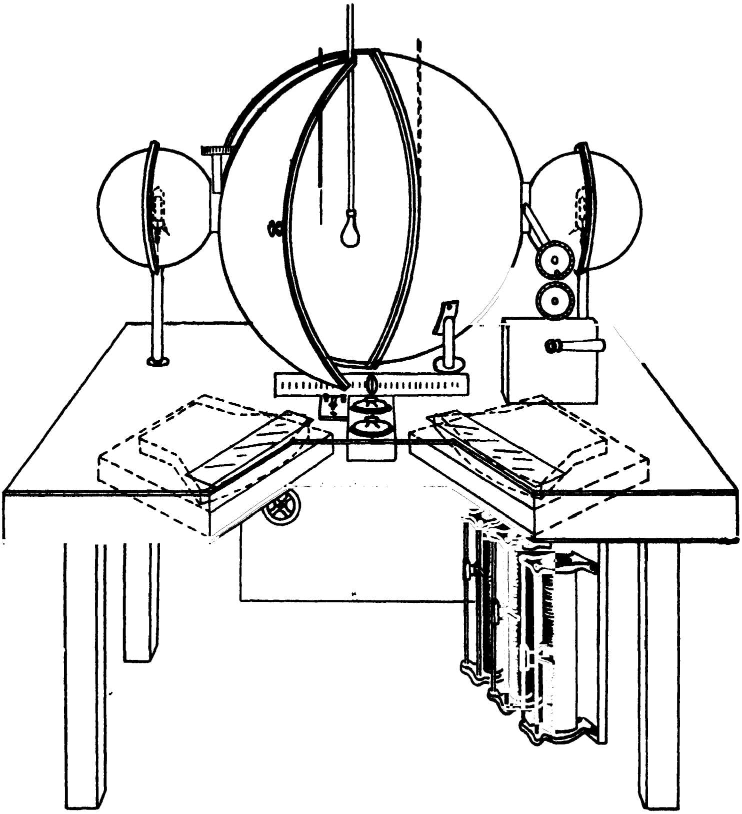


FIG. 100. COLOUR-TEMPERATURE PHOTOMETER
(*Journal of Scientific Instruments*)

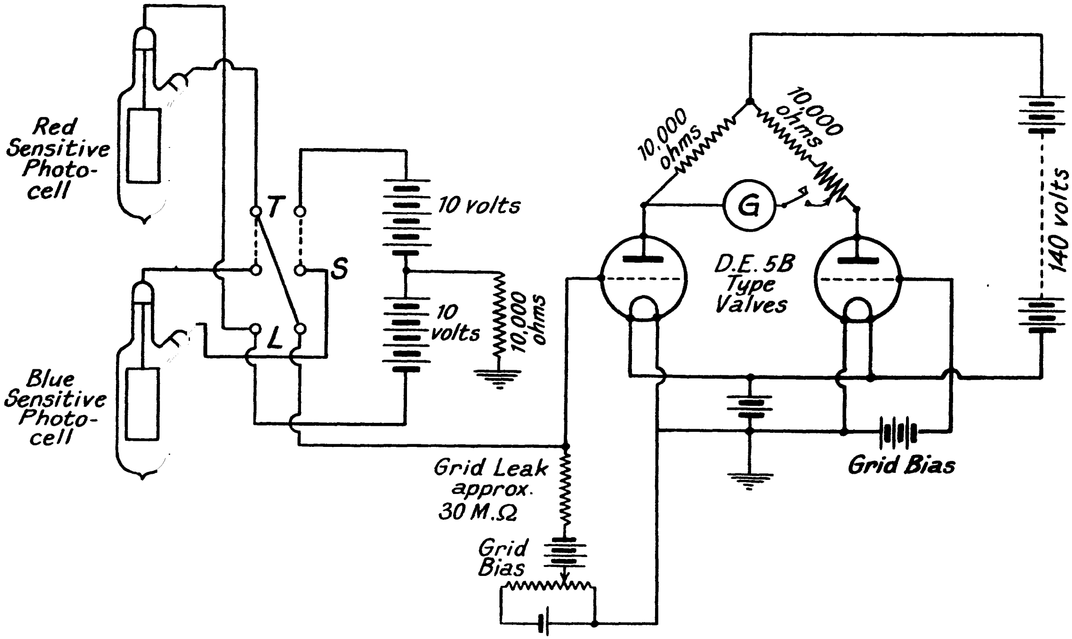


FIG. 101. CIRCUIT DIAGRAM OF PHOTOMETER
(*Journal of Scientific Instruments*)

remain equal only if the intensity changes while the colour remains the same, but they will not remain equal if the colour changes. Thus, by detecting the out-of-balance current in a bridge circuit having two cells of different types, it is possible to determine whether two sources of light are of the same colour, though they may differ appreciably in intensity. This is illustrated diagrammatically in Fig. 99, *A* being a blue sensitive cell, and *B* a red sensitive cell, null deflection of the electrometer needle *E* being secured by sliding the movable contact *C* while both cells are exposed to the radiating source. If the original source is replaced by another of different colour distribution, the electrometer will become unbalanced.

An elaboration of the arrangement, having for its object the rating of the working temperature of electric lamps, is shown in Fig. 100. It comprises two subsidiary integrators, one containing a KV 6 (potassium) cell, and the other a KMV 6 (potassium-on-copper, red sensitive) cell. This apparatus has been successfully used for measuring temperatures between 2,400° K and 3,800° K, and the complete circuit is shown in Fig. 101. In this case, one shutter setting S_1 determines the range over which measurements are to be made, and temperature observations are made by moving the other shutter S_2, the highest measurement corresponding with the largest opening. The relation between shutter opening and temperature has been shown to be

$$T_2 - T_1 = k(S_2 - S_1)$$

where T_1 and T_2 are two consecutive temperatures, and S_1 and S_2 two consecutive shutter readings. With the change-over switch in the position *L*, i.e. the two cells in parallel, lumen values can be measured on the potentiometer in the same way as in the photometer previously described. With the switch in the other position, temperature measurements can be taken.

Pyrometry.

Photoelectric pyrometry at lower temperature has also been attempted by several experimenters, but so far complete success has not been attained. For direct measurement of temperatures, small changes in the cell emission prevent as high an accuracy as is possible with optical and other forms of pyrometers being secured. For thermal control, i.e. maintenance of a furnace within specified temperature limits, the photocell is quite suitable. A standard unit can be used for this purpose, for if the cell is illuminated by the furnace radiation, the relay can be made to operate and open the heater circuit when the temperature rises above that which produces critical illumination of the cell. As soon as the furnace cools and the temperature falls below the critical value, the photocell will cause the heater circuit to be re-established. It has been shown that a regulation of 0·5 per cent in temperature can be secured at a temperature in the neighbourhood of 800° C over a period of several weeks. The critical illumination is best adjusted by a variable diaphragm over the cell. The apparatus should be provided with a suitable optical system to admit the radiation into the cell chamber. It may be necessary to use a water bath to reduce the amount of heat reaching the cathode.

Comparison of Surfaces.

The majority of colour problems in industry come under this heading, as they occur most frequently in the sorting and grading of all kinds of raw materials and finished articles. Unfortunately, the problem is not always soluble by photoelectric means. Usually it is required to predetermine at some stage in a manufacturing process whether or not two surfaces will be considered identical in appearance when subsequently examined by the eye. It is a matter of common experience that the eyes of individuals differ considerably in their powers of discrimination, and that surfaces which appear alike in daylight do not appear alike in artificial light. Even if the case is a practical one, we are forced to decide on the particular illumination under which the photocell is to make its discrimination, before it can be said to be more reliable than the eye in its powers of selection. Moreover, the eye in judging a surface is influenced by factors other than colour alone. Thus, shade and depth of colour as well as surface texture affect the final decision which is made by striking a balance between all these physical quantities. Two surfaces which appear alike, may actually differ in all of these qualities, and conversely, objects of different appearance may differ in one or all three of these qualities. To decide, therefore, by measurement, whether two surfaces will look alike, is an elaborate investigation and cannot generally be made by any routine test.

It is clear, therefore, that the design of machinery which has for its object the selection of materials and their separation according to shade of colour, may involve great practical difficulties. Machines which automatically sort such commodities as cigars, coffee beans, and eggs according to their colour, have been constructed and demonstrated. Mention has frequently been made of them in the

Press, but their adoption and general use in industry in this country has yet to be accomplished.

If, of course, the surfaces under consideration do not differ appreciably in qualities other than colour, it may suffice to use the simplest arrangement possible, i.e. that of measuring the reflecting power of the surface for white light with a single photocell. Only a trial will decide whether the differences indicated by the photocell in such a case are those it is desired to measure.

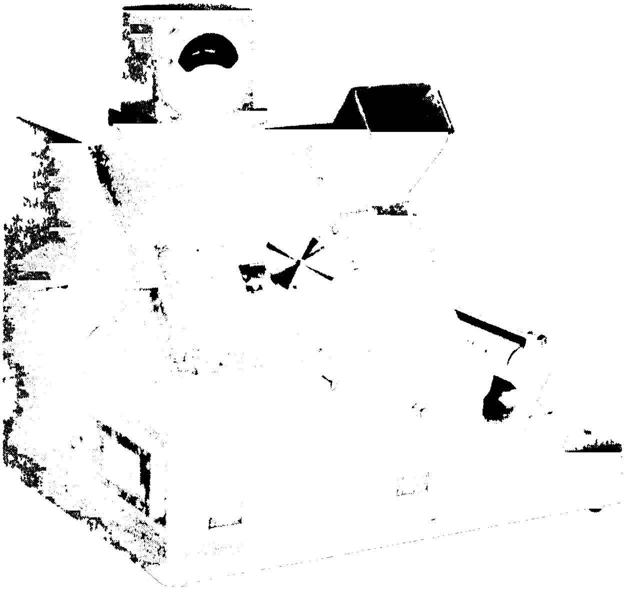
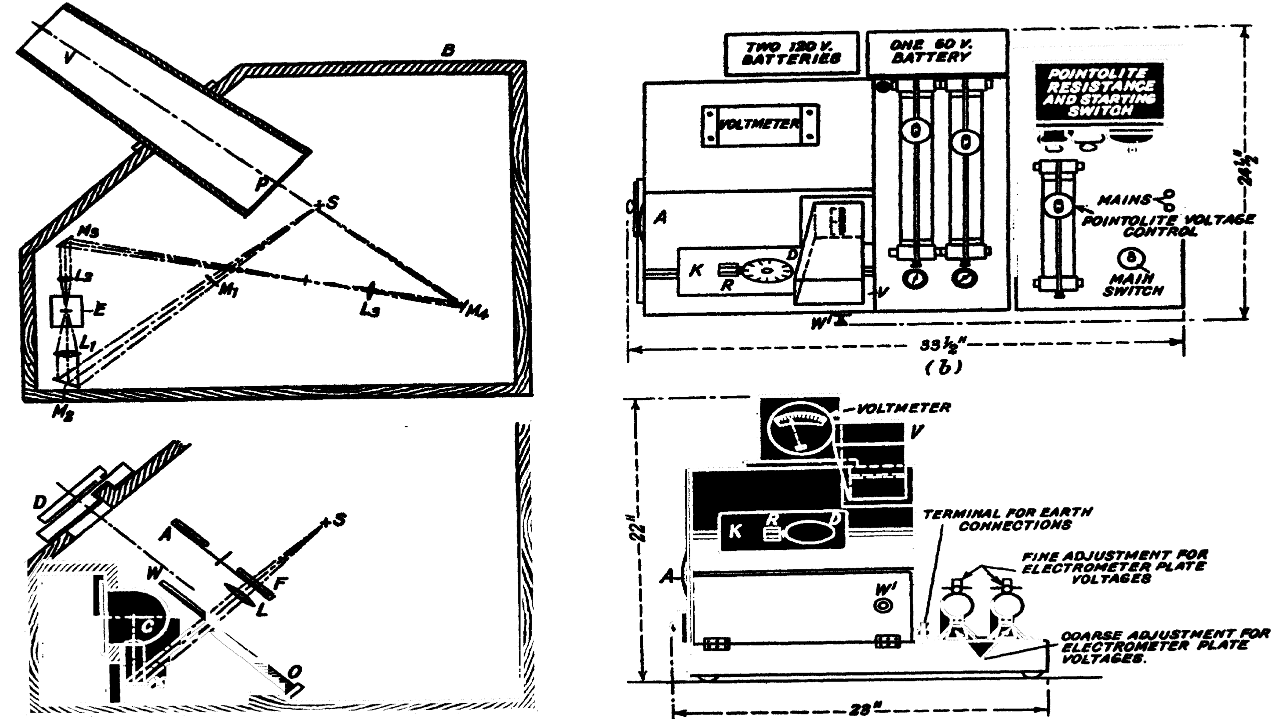


FIG. 102 BLANCOMETER
(*Adam Hilger, Ltd.*)

The Blancometer.

There is one special case of colour comparison which is of considerable importance, namely, that of matching nearly white surfaces of similar texture. It has been found that by using three appropriately chosen filters of quite broad transmission range, the reflection or transmission coefficients relative to a standard white surface as determined for the three corresponding portions of the spectrum, characterize the sample in a way which is extremely serviceable in industry and capable of detecting very small differences. Fig. 102


V
B
P
S
M3
L2
E
L1
M2
M1
L3
M4
D
A
W
C
F
L
O
TWO 120 V. BATTERIES
ONE 60 V. BATTERY
POINTOLITE RESISTANCE AND STARTING SWITCH
VOLTMETER
A
K
R
D
V
W'
MAINS
POINTOLITE VOLTAGE CONTROL
MAIN SWITCH
24½"
33½"
VOLTMETER
V
22"
K
R
D
A
W'
TERMINAL FOR EARTH CONNECTIONS
FINE ADJUSTMENT FOR ELECTROMETER PLATE VOLTAGES
COARSE ADJUSTMENT FOR ELECTROMETER PLATE VOLTAGES.
28"

Sections through Apparatus showing Optical System.
(a)

(b)

Diagram of Apparatus showing Controls.
(c)

FIG. 103. INTERNAL ARRANGEMENT OF BLANCOMETER
(*Adam Hilger, Ltd.*)

shows the Blancometer made for this purpose by Messrs. Adam Hilger, Ltd., and a brief description of its operation is given below.

Light from a lamp is reflected into the photocell, first from the surface under test after passing through two fixed optical wedges, and then after movement of the carrier, from a standard white magnesium oxide surface after passing through two adjustable wedges. The adjustable wedges enable equal deflections to be obtained in the two cases on an electrometer operating with the photocell. A similar determination using two magnesium oxide surfaces gives the zero position of the wedges. Equal deflections are obtained when the reflected lights are equal. If the gradation constants of the wedges are known, the ratio of the intensity of the reflected light in the two cases can be found.

Colour screens adjusted to give definite spectral transmissions are inserted in the path of the light, and enable readings to be taken for red, green, and blue, as well as white light. Fig. 103*a* shows the internal, and Fig. 103*b* the external arrangement of the apparatus. Light from a lamp *S* is divided into two beams by a suitable diaphragm, one beam illuminating the sample, and the other operating the electrometer. The first beam passes through a filter *F*, is collimated by the lens *L*, and traversing the wedges falls on the sample *X* at 45°, the reflected light entering the window *C* of the photocell. The specimen and the standard white surface are placed on a movable tray so that light can fall on either as desired. Attached to the carriage holding this tray are two pairs of photometric wedges, of which one pair is fixed and the other pair adjustable. The specimen is placed beneath the fixed pair, and the standard surface beneath the adjustable pair. The whole carriage is connected to the part *K*, which slides on the outside of the instrument. This part *K* carries a graduated drum *D*, which moves the adjustable wedges, complete revolutions being recorded on the counter *R*. The second beam of light is reflected from two mirrors and passes into the Lindemann Electrometer *E*, the image of the needle being projected on to the scale *P* by the optical system shown. The adjusting screw *W* projecting through the front of the case enables the electrometer needle to be kept in the field of view during large deflections. The sensitivity of the apparatus can be varied as desired by adjusting the voltages on the plates of the electrometer by means of resistances. Provision is also made to enable the source *S* to be maintained constant. The wheel *A* which carries the filters projects through the left-hand side of the case, and can be rotated by the observer. The tray containing the two surfaces is introduced through an opening close to the filter disc, the opening being constructed to exclude stray light.

If I_t = light reaching the photocell after reflection from the surface under test.

and I_0 = light reaching the photocell from the standard magnesium oxide surface,

it can be shown that $\frac{I_t}{I_0} = 10^{-\gamma(\beta - a)}$

where γ = gradation constant of the wedges,

a = zero reading of the adjustable wedges,

and β = any position giving equal deflections for any particular surface.

Hence the percentage reflection of the specimen is easily found and similarly in the cases where the colour filters are used. These percentages characterize the specimen for total reflection and for most practical purposes serve to indicate differences between nearly white surfaces. The instrument finds useful application in the examination of fabrics, powders, paints, and other raw materials.

The Toussaint Colorimeter.

This instrument employs a set of six Wratten filters which are interposed in turn in the path of a beam of light from a lamp. After passing through the filter, the light is allowed to fall first on to the surface under inspection, and then on to a standard white surface, in each case being subsequently reflected on to the photocell. Valve amplification is employed to obtain a reading on a milliammeter. With each filter, two such readings are obtained, one for the test surface and one for the sample, the latter being subsequently expressed as a percentage of the former. The six percentage values corresponding to the six filters are then plotted as a colour curve and serve to show some indication of differences in samples which are supposed to be the same. No provision is made in this instrument for difference in surface texture, so that these must necessarily be the same as that of the standard. The filters have fairly narrow transmission bands, so that the amount of light they absorb is rather high. The makers apparently do not restrict the use of this instrument to nearly white surfaces, but claim that it is capable of giving correct indications for any coloured surface. As, of course, colours which appear alike may have widely differing spectral constituents, it is possible to conceive of cases where the distinction of colour could

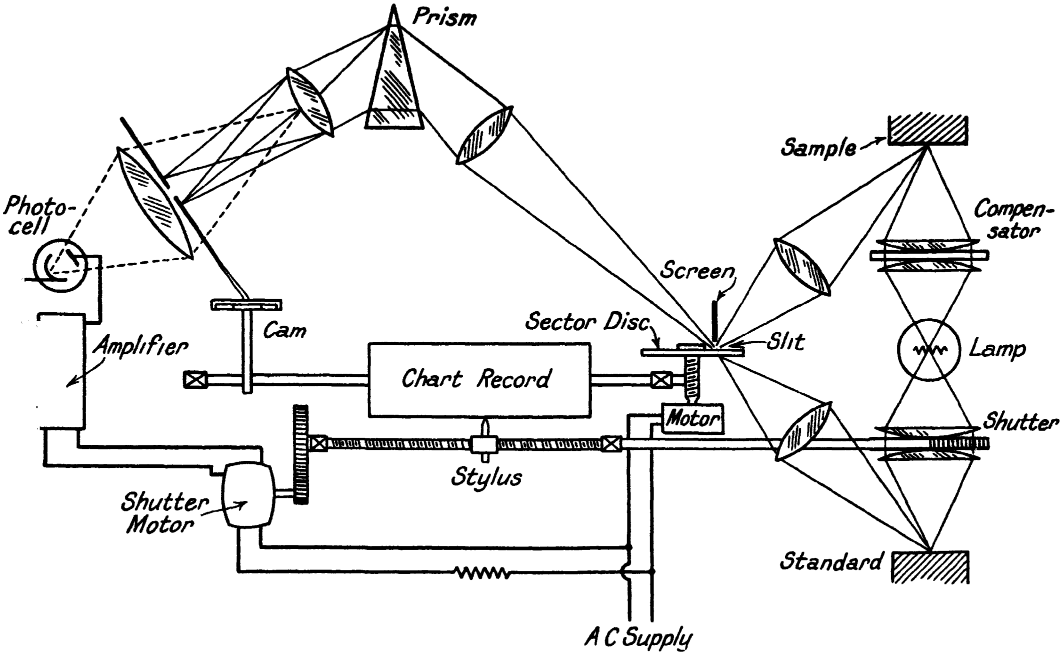


FIG 104 A C HARDY'S COLOUR ANALYSER
(*Journal of the Optical Society of America*)

be approximate. However, this instrument is in use by a number of manufacturers whose experience is that it gives useful assistance in matching coloured surfaces, with more accuracy than is possible by other means.

Colour Analyser.

A more elaborate method of comparing the colour of a surface with a standard surface has been devised by A. C. Hardy (*Jour. Opt. Soc. Amer.*). The specimen and the standard white surface are both illuminated by the light from a gas-filled ribbon filament lamp, the light reflected from each surface being thrown in turn on to the slit of an optical dispersing system which produces a long spectrum. The change of light on the slit is accomplished by means of a motor-driven disc interposed in the path of the reflected rays. This disc is divided into sectors, alternate sectors being removed, and those remaining being highly polished. The light falling on the optical system is thus alternately reflected from the sample and transmitted from the standard surface. It is arranged that the two spectra so formed by the dispersing system are coincident, and a narrow band of each of the spectra is selected by another movable slit and falls on the photocell and causes a pulsating current in the cell circuit if the two beams differ in intensity at the particular point of the spectra opposite the slit. The A.C. component of the current, after amplification, is fed into the field of a small motor driving the recording chart, the armature of the motor being supplied from an independent source. The direction of rotation is determined by the relative intensities of the two beams. The motor controls a diaphragm varying the illumination on the standard surface, so that the intensity of the two beams is automatically kept in balance. The stylus records this diaphragm position on the chart, while the rotation of the drum changes the portion of the spectrum admitted to the photocell. In this way the whole of the spectrum can be covered. Since equality of response to light from the two surfaces is indicated by no output from the amplifier, this method of recording is free from the usual objections which accompany the use of valve amplification for quantitative measurements.

CHAPTER X

MISCELLANEOUS APPLICATIONS

ALTHOUGH the principal circuits involving photoelectric cells in general use have been dealt with in the preceding chapters, there are several other applications which are certainly interesting and sometimes particularly useful in special cases, though they are used less frequently than those previously described.

It is intended, therefore, in these last few pages to draw attention to the application of the photocell to special problems of entirely different natures from those already considered. Thus, interest may be stimulated in the possibilities of the photocell in new fields, and attention given to other problems which may be solved with their aid. We propose, therefore, to deal with some of these special applications without any regard to continuity, or their relation to each other.

The method of passing the photoelectric current through a very high resistance in series with an electric supply, and measuring the potential difference between the ends of the resistance by means of an electrometer—a method of very general application—can be modified to great advantage in some instances by the substitution of the impedance of a thermionic valve in place of the usual wire or synthetic material resistance. The chief advantage of this modification is that it is possible to obtain a variable equivalent resistance of almost any magnitude, and so secure very delicate control, by altering the filament temperature of the valve. In addition, there is the advantage that for a given mean current the change of potential corresponding to a given change of illumination is greater when the thermionic valve is used. In the usual method, employing a resistance, although it is theoretically possible to increase indefinitely the potential difference across the resistance by increasing the value of the latter, a limit is set by the decrease in current, whereas with the valve it is possible to increase the current by using potentials nearer the glow discharge point of the cell without danger of flashing.

Details of the characteristics and performance of cells under such methods of operation will not be further discussed here, and the reader is referred to the original paper for full details.

Ticking Circuit.

One particular variation of this circuit which has been used considerably is, however, of some importance, and is illustrated in

Fig. 105. The cell P is connected in series with the anode impedance of the valve V, transformer T, and supply voltage B, which must be chosen considerably above the glow potential of the cell. The average current flowing in the circuit will be determined entirely by the emission of the valve and, consequently, is controlled by the adjustment of the valve filament current. If we assume the cell P to be kept dark, no steady photoelectric current will pass through it if this condition has been previously secured by the adjustment of the filament current of the valve V. Hence, the capacity C, together with the interelectrode capacity of the cell, will charge up until the glow potential of the cell is reached.

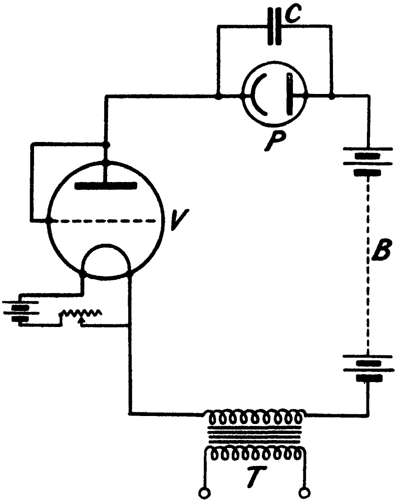


Fig. 105. Ticking Circuit

A discharge of short duration will, at that moment, pass through the cell during which period the potential of the condenser will fall till the stopping potential (*cf.* Ch. I, p. 11) of the cell is reached, when the discharge will cease. The persistence of the discharge is prevented by the current limiting valve V, the filament emission of which has previously been adjusted to a value less than that of the glow discharge of the photocell. When the stopping potential is reached, the condenser will immediately begin to recharge and repeat the process.

Thus a series of current pulses will pass through the primary of the transformer T, and may be detected by headphones as a series of clicks or, if of sufficiently high frequency, as a musical note in the telephones connected to the secondary of the transformer. If, now, light falls on the cell, some current will pass before the glow discharge voltage is reached. If the greatest current, short of the glow discharge which can normally pass through the photocell, exceeds the emission from the valve filament, the glow discharge voltage will never be reached, but the same average current as before will pass as a steady continuous current, and there will be no e.m.f. induced in the transformer secondary, and no note will be heard in the telephones. Any change from one light intensity to a lower light intensity will thus cause a decrease in the frequency of the note heard, and very small light changes can be detected by this means.

The sensitivity of the arrangement is high, 0·0001 lumen being easily detected, and the circuit is, moreover, not seriously affected by slight changes in the applied voltage, these differences being taken up by the valve *V*. In cases where it is required to detect small changes of light, it is usually desirable to adjust the aperture over the cell so that the current pulses can be detected separately, and then to count them over a fixed interval, say, a minute, repeating the observation after the light change has taken place. A bright "emitter" valve is preferable to the more modern types owing to the fact that its emission is more easily saturated. With this circuit there is the great advantage that, unlike most other methods, insulation resistance is not of first importance, providing that the insulation resistance of the valve is high compared with that of the cell.

FIG. 106*a*. UNITS INCORPORATING THE TICKING CIRCUIT
(*General Electric Co., Ltd.*)

Fig. 106*a* illustrates the circuit incorporated in two units, the left-hand one housing the photocell. This equipment is portable and designed to operate from an ordinary wireless accumulator and H.T. dry battery. Fig. 106*b* shows the circuit diagram of the two units.

The circuit just described is most sensitive when used with the spherical type of cell of the potassium type. Plane cells have been used in cases of simple light detection. The existence of dark current prevents the circuit from functioning, hence, it is not suitable for use with the more modern types of cell. Obviously, if desired, the telephone currents described above easily permit of subsequent amplification, so that it is possible to dispense with an observer, and either record automatically or operate relays by the minute light changes.

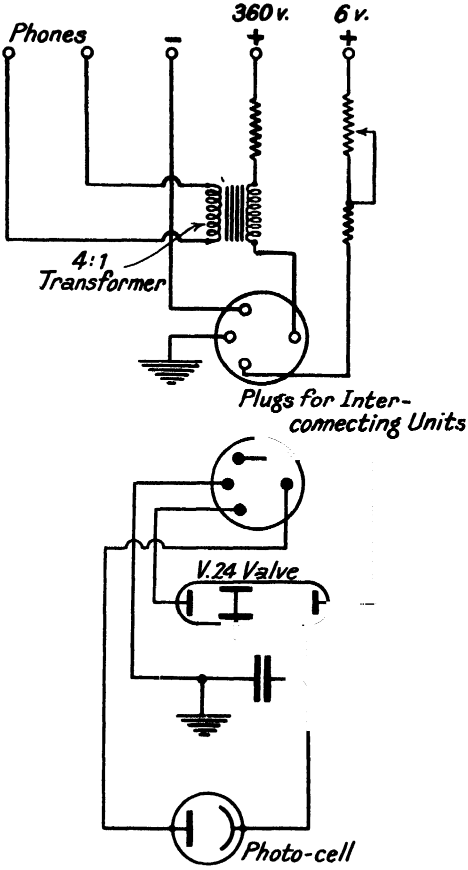


Fig. 106*b*. The Circuit of The Units Shown in Fig. 106a

Fig. 107 illustrates a circuit arranged for two stages of amplification, together with the necessary rectifying apparatus, to enable the whole to be operated from A.C. supply mains. If the change in illumination is large, the change in anode current in the output valve will be from zero to a maximum, and the standard type of relay previously described can be conveniently used. If, however, the variation of light is small, involving only a change in a very low frequency, a specially designed relay will be necessary. For instance, it might be necessary for it to remain closed when the frequency of the current pulses are one or two a second. Such a relay can conveniently consist of a pivoted lever not supported at its centre of gravity, and held in position against its tendency to rotate about its point of support by an electromagnet through which the current pulses pass. The centre of gravity of the lever is adjustable by means of a movable weight, so that pulses of a given frequency just prevent rotation. Any decrease in frequency permits the weight of the lever to overcome the attraction of the electromagnet, to rotate and close a contact at the end of its travel. An independent means of resetting the relay is, of course, necessary. This type of circuit, which is frequently known as the "Ticking" circuit, has been successfully employed in detecting fine smoke and dust by the light these impurities scatter: also in determination of the dew point, of turbidity, and the presence of faint precipitates, in fact, in most applications where extremely small light changes are expected.

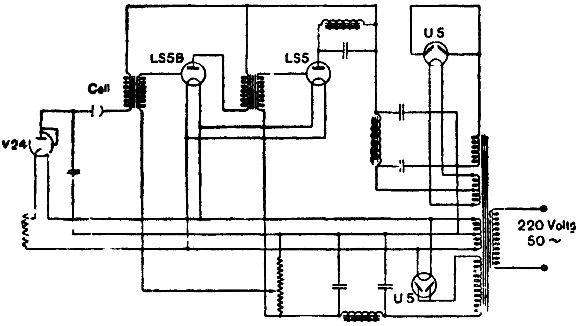


Fig. 107 A.C. Mains Amplifier Using Ticking Circuit

Interrupted Light.

Another circuit which is used for the detection and recording of very weak light changes follows closely upon the lines of the circuit of the picture telegraph transmitter. The light falling on the cell is passed through holes in a rotating disc, and is thus interrupted at a frequency which enables the resulting photoelectric current to be amplified by a low frequency valve amplifier. The output of this amplifier can then be measured on a rectifier meter, a valve voltmeter, or a recording meter. An excellent example employing this circuit is shown in the Baird Noctovision, a system developed for the location of lights in a fog, or infra-red ray signalling over considerable distances. Here the light from the distant source falls on the cell cathode through a long-sighting tube. The light passes through the holes in a large rotating disc, so that it is interrupted at about 1,000 times a second. A high-gain amplifier then increases the photoelectric currents sufficiently to light a small glow discharge lamp in the amplifier. The whole gear is mounted in a waterproof box on a turntable, and the observer watches the discharge tube through an eyepiece, rotating the apparatus at the same time. In the position where the incoming beam falls directly down the tube, the latter glows and the observer reads the bearing of the light beam

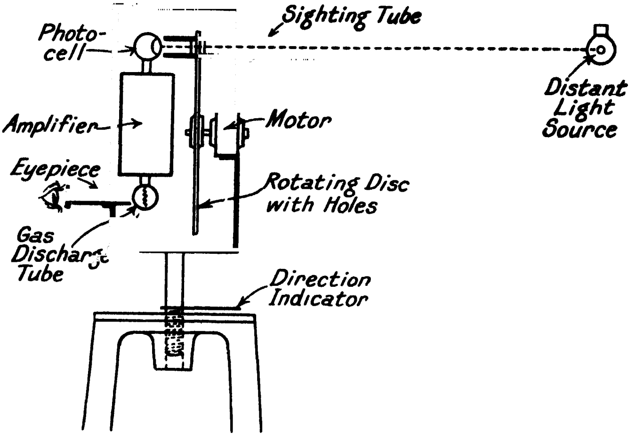


FIG. 108. BAIRD'S INFRA-RED DIRECTION FINDER
(Television Press, Ltd.)

on the turntable scale. The infra-red radiation of a motor-car head-lamp with an ebonite filter has been detected and located by this apparatus over a distance of three miles.

Methods of Increasing Sensitivity.

Cases sometimes arise where the conditions of the installation are such that the standard amplifier is insufficiently sensitive to operate with a fair margin of safety. This usually occurs when the distance separating the source of light and the photocell is large, and where even with a carefully designed light source the illumination of the cell cathode is insufficient. As already explained in Chapter II, substituting a larger lamp at the source is not always a solution, as this invariably means a larger "point" source and, therefore, a larger image of the filament at the amplifier end, which generally results in the same intensity of light over a larger area, and is consequently no more efficient. Any light falling outside the aperture of the amplifier case is obviously wasted and, in addition, there is clearly a limit to the size of lamp which can be economically used. In most cases where a beam of light is the controlling illumination, increased sensitivity of the set can be secured by fitting a double convex lens to the apparatus, so that some of the light normally falling outside the aperture is converged on to the cathode, and the area of the light sensitive surface is virtually increased. It is to be noted that for diffused light practically no increase in sensitivity will be obtained by the addition of a lens, e.g. for apparatus controlled by the general illumination or diffused daylight inside a building.

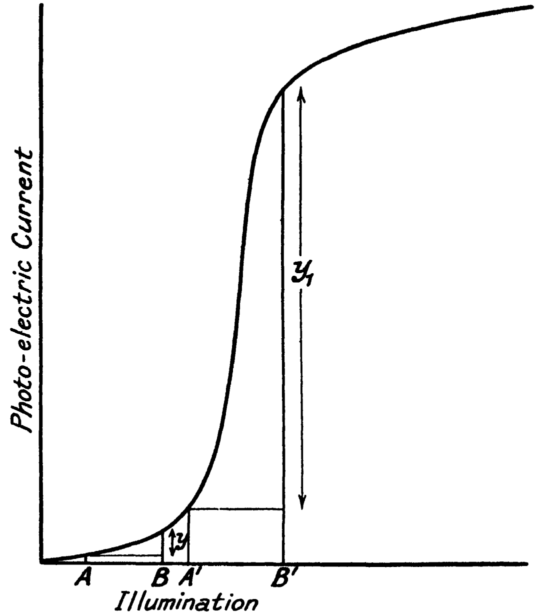


FIG. 109. PRIMING THE PHOTOCELL

Other methods consist of applying a higher potential to the photocell or "priming" the cell with an auxiliary light.

As the resistances of the amplifier are usually fixed, the voltage on the cell for a given supply voltage cannot be altered, so that the effect of increasing the potential applied to the cell can be secured only by the substitution of a cell with a lower glow discharge potential. This may have two obvious disadvantages if applied without caution: firstly, the operation of the cell too near its flashing point tends to curtail its useful life and, secondly, the tendency to glow spontaneously if a sudden increase in illumination occurs is increased, the nearer the cell is operated to its glow potential.

The principle involved in priming the cell by an auxiliary light source will be readily understood from Fig. 109, which shows the curve connecting illumination and photoelectric current when the applied voltage is just below the stopping potential of the cell. It is clear that if AB represents a given change in illumination on the horizontal axis, a much greater value in photoelectric current will occur if the illumination change occurs over the range A^1B^1 than over the range AB. Practically, this advantage may be secured by fitting a small lamp of the 12-volt, 6-watt, or smaller type inside the amplifier, and controlling the filament temperature by means of a finely divided sliding resistance, so that the filament may be operated at any temperature above dull red heat. Very fine adjustment can be secured providing the amplifier is operated from batteries, but voltage changes in the supply will most probably prevent full advantage being taken of the method if an attempt is made to work the amplifier from D.C. mains. The advantage of this method becomes even less on A.C. supply.

Priming can, of course, be secured by an external illuminant. It may be fitting to quote here two instances where such an arrangement is particularly useful. Previous mention (Ch. II) has been made of the fact that, owing to the existence of a small grid current in the grid circuit, which must of necessity be neutralized before the photoelectric current can bring the grid to negative potential, a larger illumination is required to reduce the anode current to zero than is required to maintain it at zero. Hence, in the case where it is desired to detect the presence of substances of feeble opacity, such as faint smoke, the preliminary adjustment being made by an aperture over the photocell, the intervention of the smoke will operate the relay, but when it clears away, the light which was previously sufficient to maintain the valve grid at zero or slightly negative is insufficient to restore it to this condition and, therefore, to reset the circuit for the next detection. To overcome this difficulty an extra set of contacts can be fitted to the relay, and as soon as it is operated by the smoke, an auxiliary lamp is brought into circuit, so that when the smoke clears, the additional illumination is sufficient to restore the set to its original state. It is obvious that the increase in illumination must be small, and is best determined by trial, otherwise it may be sufficient to penetrate the impurity and release the relay during the period of detection, so that the latter will switch in and out very rapidly. The simplest method is to operate the lamp used as the main illuminant, in series with an adjustable resistance which is short circuited when the relay is energized, thus giving the required increase in light to reset the apparatus.

An independent light source has an important application in another direction. This is perhaps best illustrated by an example, though a little reflection will show that it has many applications. Referring back to Fig. 33, the two-cell circuit there described is of perfectly general application to many miscellaneous problems, inasmuch as has already been explained when the amount of light on cell *D* is greater than the amount of light on cell *C* the relay will be energized, and when the reverse condition obtains, the relay will not be energized. Descriptions of the utility of this circuit have already been given in connection with gas detection, etc. There is, however, no intermediate position which the relay can possibly assume during the transition states, i.e. when the light on both cells is equal, or when both cells are dark, and under these conditions the relay will probably be unstable and its operation in either direction a matter of chance depending possibly on its immediately preceding operation, or some other outside factor.

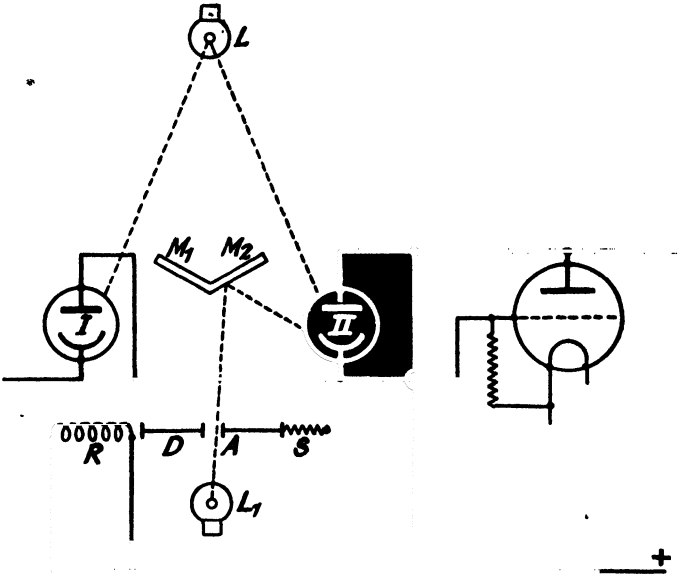


FIG. 110. THE OSCILLATING BRIDGE CIRCUIT

It is possible by the use of an auxiliary light source to provide a third state of the relay corresponding to an intermediate state of the exciting illumination, e.g. darkness on both cells, or equal illumination on both cells. A special relay might be constructed to respond under such conditions, but, in general, such relays are unstable in the neutral state, and only stable when making contact at one side or the other.

Fig. 110 illustrates diagrammatically the principles involved to overcome the difficulty. L is the principal source of illumination; D is a shutter in which is an aperture A. D can move towards the left under the attraction of the relay coil R, to the armature of which it is attached. This motion moves the beam of light from the auxiliary lamp L_1 from the mirror M_2 on to the mirror M_1. Light falling on mirror M_2 is reflected on to cell *II*, and increases the main illumination received from L_1. Similarly, light falling on M_1 is reflected on to cell *I*. The shutter D is normally held towards the right by the tension of the spring S when R is not energized.

Assume first of all that the illuminations on each cell from L are equal. The additional light from L_1 reflected from the mirror M_2 will make the total light on cell *II* greater than the total light on cell *I*. Hence, the relay R will be energized and attract armature D, moving the slot A towards the left. This will shift the auxiliary light from M_2 to M_1. The total light on cell *I* will now be greater than that on cell *II*, so that the relay will be released and the original state of the apparatus restored, when the cycle of events will be repeated.

The relay will then alternate between the ON and OFF position, and thus indicate the transition state between extreme differences of light on the two photocells.

Assume now that the illumination of cell *I* from the lamp L_1 is, owing to the interposition of some absorbing or opaque material, much less than that on cell *II*. The relay R will be energized and move the auxiliary illumination as before from M_2 on to M_1, thus increasing the illumination on cell *I*. As, however, the light from L_1 is assumed small compared with the difference of illuminations of cells *I* and *II*, the total light on cell *I* will still be less than the total light on cell *II*, and the relay will remain energized and not revert to its original condition. Similarly, it will be seen that if the light on cell *II* from lamp L is much less than that on cell *I*, the relay will remain stable in the OFF position.

It is thus clear that there are two definite positions of the relay corresponding to extremes of light on the cells *I* and *II*, and another definite state of the relay which characterizes the condition of approximate equality of illumination. By careful adjustment of the intensity and position of the source L_1 the transition stage can, within limits, be made as broad or narrow as desired. It will be noted that in the example described the same relay performs the function of giving the signal to the external circuit and of controlling the performance of the auxiliary source *L*. There is, of course, no reason why an independent relay should not be used for this purpose if desired.

Change of sensitivity of the standard amplifier can be also effected by altering the grid leak. In the example previously cited, instead of allowing the relay to short circuit a resistance in series with the main illumination, it can be allowed automatically to change the grid leak to one of higher value, thereby increasing the sensitivity of the circuit sufficiently to bring about a resetting to its original state when the light interrupting substance has been removed.

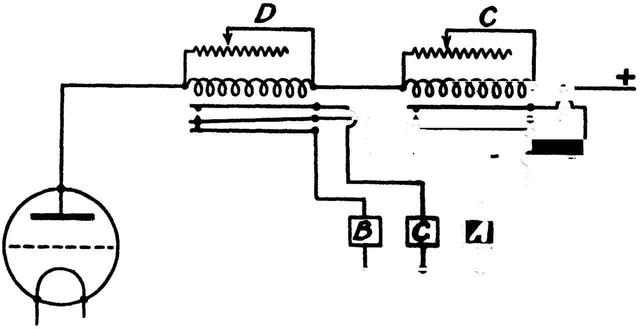


FIG. 111. SELECTIVE RELAY CIRCUIT

The difficulty of obtaining constancy in high resistances (1–400 megohms is the range usually required), and securing any kind of satisfactory adjustment on them, together with the desirability of keeping the grid circuit free from additional connections to minimize insulation troubles, makes this method of control less satisfactory than the others described.

In cases of simple detection of light the anode current is either a maximum or zero, so that no adjustments in the anode circuit are possible to secure variation. If, however, the valve is being operated between comparatively narrow limits on the straight portion of its grid volts—anode current characteristic—as in the case of temperature control (*cf.* page 170), it may be desirable to enable the relay to pull in and out at currents which differ only by a small amount. Normally, of course, the retentivity of the core causes the relay to release at a considerably lower current than its operating current and, consequently, the current value at which the relay pulls in on a rising current is lower than the value at which it releases on a falling current. Thus external control is limited by the extreme values of these currents.

If, however, an auxiliary set of contacts is arranged on the relay (*cf.* page 33) to close a resistance in parallel with the operating coil, as soon as the latter is energized then, providing this resistance is suitably adjusted, the "ON" and "OFF" positions can be made to approach as near to one another as desired. As in the case of the auxiliary illumination, the value of this resistance will obviously have a lower limit at which the relay armature will "hunt" by rapidly switching in and out, and the arrangement will be useless.

Selectivity of current range in quantitative work can be secured by means of a series arrangement of relays with suitable controlling shunts. As an example, suppose it is required to actuate three independent devices, *A*, *B*, *C*, respectively, over the anode current ranges 0–3, 0–8, 8–10 milliamps, respectively. Relays *C*, *D* operate through the adjustment of their shunts at 3 and 5 milliamps, respectively (Fig. 111). The introduction of the Gas-filled Relay enables this scheme to be carried out very successfully, for now a large number of selective relays may be adjusted and operated from one tube. Small telephone type relays sometimes have a definite overlap of switching on and switching off currents, and this difficulty can be overcome by the use of tubes giving larger output currents, as the adjustments become less critical.

BIBLIOGRAPHY

Photoelectric Cells, Campbell & Ritchie. (Pitman & Sons.)

Photoelectric Phenomena, Hughes F. and du Bridge. (McGraw Hill.)

Photocells and their Applications, Zworykin & Wilson. (John Wiley & Sons.)

Photoelectricity, Allen. (Longmans Green & Co.)

Ions, Electrons, and Ionizing Radiation, Crowther. (Arnold & Co.)

GENERAL REFERENCES

Electronics. (McGraw Hill Publishing Co.)

Ann. d. Physik, 1889, vol. xxxviii, p. 497; 1890, vol. xli, p. 161 "Elster and Geitel."

"Valve Relay Circuits." See British Pat.

"Valve Bridge Relay," Bretano, *Nature*, 1921, vol. cviii, p. 523.

"Grid Glow Tubes," Knowles, *Electric Journal*, 1928, vol. xxvi, p. 176; 1930, vol. xxvii, p. 116.

"Thyratrons," Hull, *General Electric Review*, 1929, vol. xxxii, April; 1929, vol. xxxii, July.

"Automatic Photographic Printing," *Electronics*, 1930, June.

"Counting Automobiles on Ambassador Bridge," *Electronics*, 1930, June.

"Photocells in Automatic Weaving," *Electronics*, 1930, November.

"Alarms for Paper-making Machines," *British* Pat. 324895, 365184.

"Automatic Drinking Fountain," *Electronics*, 1930, November.

"Time Lag in Photoelectric Cells," Wheatstone, *Phil. Mag.*, 1931, vol. xii, July.

"Ground Noise in Sound on Film," *Electronics*, 1930, October.

"Influence of Slit Width on Reproduction," von. Hortel, *Funk*, 1930, vol. xxxvi, p. 595.

"Talking Film System," *Bell System Technical Journal*, January, 1929.

"Talking Film System," *A.E.G. Journal*, January, 1930.

"Talking Film System," *Electric Journal*, November, 1929.

"Talking Film System," *E.T.Z.*, November, 1929.

"Coupling Cell to Amplifier," Thomas, *Proc. Ply. & Opt. Soc.*, May, 1930.

"Facsimile Picture Transmissions," Zworykin, *Pro I.R.E.*, 1929, vol. xvii, p. 536.

"Developments of Facsimile Telegraphy," Ranger, *P.I.R.E.*, 1929, p. 1564.

"Photographic Problems in Picture Telegraphy," Newton, *Television*, 1930, February.

"The Fultograph Picture Broadcasting," *Wireless World*, 1927, 1928, vol. ii, p. 555.

"Television," Ives, *Bell System Tech. Journal*, 1927, vol. vi, p. 551.

"Multi-channel Television," Ives, *J. Opt. Soc.* (*America*), 1931, January, vol. xxi, p. 2.

"Developments in Television," Mitchell, *J. Roy. Soc. of Arts*, 1931, vol. lxxix, p. 616, May.

"Image Transmission for Two-way Television," *Bell System Tech. Jour*, 1930, July.

"Multi-channel Television," Brown, *Wireless World*, 1930–31.

Television, Dinsdale. (Pitman & Sons, 1926.)

"Lindemann Electrometer," Lindemann and Keely, *Phil. Mag*, 1924, vol. xlvii.

"Colour Analyser," Hardy, *J. Opt. Soc.* (*America*), 1929, vol. xviii, p. 96.

"Photometry," Research Staff of the G.E.C., *J. Sci. Inst.*, 1927, vol. iii, p. 2.

Photographic Photometry, Dobson. Oxford University Press, 1926.

"Measuring Diameter of Yarn," *British Research Association of Woollen and Worsted Industries*, 1928.

"Chemical Titration," Müller and Partridge, *Ind. and Eng. Chm.*, 1928, vol. xx, p. 423.

"Ultra Violet Light Meter," *Journal American I.E.E.*, February, 1930, vol. xlix, p. 113.

INDEX

ADVERTISING, 70
Alarm for valve failure, 49
——, multi-point, 52
——, testing, 53
——, thermometer, 69
——, water gauge, 68
Alkali metal-emission curves, 4
American circuit, 20
Amplification valve, 18
—— —— gas-filled relay, 28
Amplifier unit, 26
Automatic drinking fountain, 80

BACKGROUND noise, 93
—— silent recording, 96
Baird direction finding, 181
—— television system, 139
Ballistic galvanometer, 17
Barium, 4
Barretter, 62
Bartlane picture transmission, 127
Belin picture transmission, 126
Bell System television, 140
Blancometer, 172
Boiler gauge alarm, 69
Bridge circuit, 165
—— —— in photometer, 169
—— —— oscillating, 185
Burglar alarm, 37
—— —— infra-red, 50

CADMIUM, 6
Caesium, 4
—— colour emission, 5
Cathode ray television, 143
—— construction, 13
——, relative sensitivity, 8
Cell characteristics, gas-filled, 12
—— ——, vacuum, 7
Circuits, American, 20
——, amplification, 17–32
——, four electrode valve, 24
——, G.E.C., 22
——, light modulation, 70
——, safety, 49
——, two-cell, 57
Clockwork delay switch, 75
Colorimeter, Toussaint, 174
Colour analyser, 176
—— of surface, 171
—— measurement, 166
—— television, 151

Contactor power, 34
Control of electric signs, 72
—— of models, 81
—— of printing machines, 66
Counting installations, 39
——, multiple, 43
——, selective, 41
Coupling of cell, 109
Coupon checking, 67

DARK current, 15, 20
Decibel notation, 106
Delay action switch, 76
Density meter, 157
Detection of flashes of light, 29
—— of light, 18
—— of smoke, 60
Dimension of sound films, 87
Discharge, glow, 10
Distortion in television, 147
Dosage meter, 160
Dot transmitter, 116
Dual frequency transmission, 133

ELECTROMETER, 17
Electroscope, 17
Emission of alkali metals, 4
—— of thin films, 5

FOUR electrode valves, 50
Frequency characteristic, 104
—— ——, method of testing, 105
—— ——, response of cells, 108
Fulton system transmitter, 120

GALVANOMETER circuits, 17
Gas detector, 56
Gas-filled cells, 10
characteristic, 12
relay, 28
Gauge indicators, 68
——, water boiler, 69
Glow discharge, 10, 13
Gramophone Co. television, 142
Grandeur film, 91
Grid current, 20
—— glow tube, 27

HALLWACHS' effect, 1
Hardy colour analyser, 176

ILLUMINATION for photocells, 35

Infra-red direction finder, 182
—— filters, 37
—— —— for films, 103
Interrupted light, 181
Invisible ray operation, 36
Insulation leakage, 14
Ionization, 10

LAG-TIME, 107
Lamps for photocells, 35
——, life of, 102
——, photometry, 164
Leaflet distributor, 79
Leakage current, 9, 20
Lift gate control, 50
Light modulation, 70
—— sources, 35
—— —— for smoke detection, 62
Lithium, 4
Lumen, 8

MACHINE control, 50
——, speed of, 47
Mains operated relay circuit, 23
—— variation, 61
Microphotometer, 153
Mihaly soundhead, 100
Models, circuits of, 82
——, control of, 81
Modulation by Neon tube, 70
Multiple point alarm, 52
—— recording, 43
—— tone transmitter, 128

NIPKOW disc, 137
Noctovision, 181
Noise background, 93
Novelties, 79

OPTICAL systems films, 98
—— —— picture telegraphy, 118
Oscillating bridge circuit, 185

PAPER-MAKING machines, 66
—— bag printing, 67
Phase changing circuit, 31
Photo tube, 27
Photographic density meter, 159
Photometer, 160, 164
—— bridge circuit, 165
—— colour temperature, 168
——, portable, 163
——, ultra-violet, 162
Primary emission, 8
Pritchard gas detector, 56
Protective resistance, 11
Pyrometry, 170

QUANTITATIVE measurement, 26

RECORDING, microphotometer, 153
——, multiple, 43
——, one-way, 42
——, racing, 44
——, rotation, 48
——, selective, 41
——, silent background, 96
——, smoke density, 61
——, variable area, 91
——, —— density, 91
Relay, gas-filled, 28
——, power, 34
——, self-locking, 51
——, telephone, 33
Rubidium, 4

SCANNING distortion, 147
Schrot effect, 97
Selective relays, 187
Sensitivity—methods of increasing, 182
Shafts, speed of rotation, 47
Siemens Karolous cell, 118
Signs, control of, 72
——, —— by motor-cars, 74
Silent background recording, 96
Slit, area exposed, 92
Smoke detection, 59
—— —— apparatus, 63
—— —— recording, 65
Sound tracks, 94
Soundheads, 98, 100
Source of light, 35
Stopping potential, 13
Strontium, 4
Surfaces, comparison of, 171

TALKING films, explanatory, 86
Television, Baird, 139
  Bell system, 140
  cathode ray, 143
  colour, 151
  —— characteristics, 141
  experimental, 138
  Gramophone Co.'s, 142
Telephone relays, 33
Tell tales, 55
Testing alarm circuits, 53
Thermometer alarm, 69
Thin film cathode, 6
Thyratron, 28
—— characteristics, 29
—— circuits, 32
Ticking circuit, 177
—— ——, mains-operated, 181
Time lag, 15
Timing races, 44
Toussaint colorimeter, 174
Transmitters, Bartlane, 127

Transmitters Belin, 125
——, Fulton, 123
——, two-frequency, 133
Two-cell circuit, 57

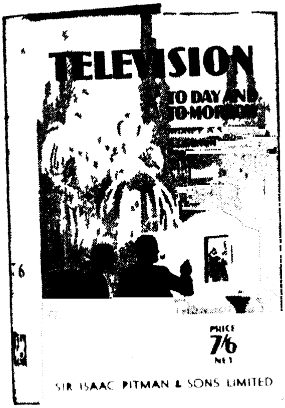
ULTRA-VIOLET measurement, 160
Uniform energy radiation, 6
Unit as a protection, 50
——, photocell relay, 26

VACUUM cell, 7–9
Valve, thermionic relay—
——, American circuit, 20
——, all mains, 23
Valve, battery circuit, 20
——, electrometer, 165
——, four-electrode, 24
Variable area recording, 91
—— density recording, 91
Vinten soundhead, 98

WATER gauge, 68
—— purifier, 58
Wave length emission curves, 4
—— units, 3
Westinghouse optical system, 119
Window display unit, 77
Wow-wow, 92

PRINTED IN GREAT BRITAIN AT THE PITMAN PRESS, BATH
C3—(5758)

Read How It Is Done!



TELEVISION

TO-DAY AND TO-MORROW

By

SYDNEY A. MOSELEY and
H. J. BARTON CHAPPLE
Wh.Sc., B.Sc.(Hons.),
A.C.G.I., D.I.C., A.M.I.E.E.

With a Foreword by
JOHN L. BAIRD

A popular account of the invention and development of television. In this second edition information is included regarding the big screen, which created a sensation on its introduction at the London Coliseum, and at the Scala Theatre, Berlin; while complete details are given of the commercial "Televisor" set which has been produced since the publication of the first edition of this book.

SOME LEADING PRESS OPINIONS

"It is certainly one of the most readable of the many books on this subject which have appeared recently The book is well illustrated and some of the reproductions of untouched photographs of various subjects as they appeared on the screen of a Baird Televisor receiver are astoundingly good —*Armchair Science*

"Elucidates in simple language the methods employed to-day for transmitting and receiving the images of living, moving subjects by wire and wireless"—*Popular Wireless*

"Every broadcast listener will be enthralled by its marvels"—*The Listener*

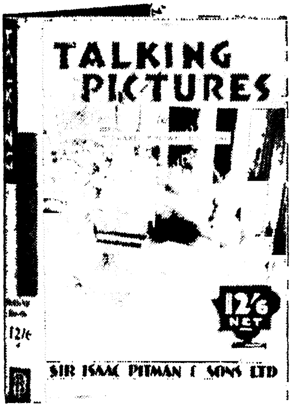
"No one interested in the subject should miss this book, it is lucid, informative, and practical —*Public Opinion*

Second Edition

In demy 8vo, cloth gilt, 190 pp., illustrated. 7s. 6d. net.

SIR ISAAC PITMAN & SONS, LTD, PARKER STREET, KINGSWAY, W C.2

TALKING PICTURES



By

BERNARD BROWN,
B.Sc. (Eng.)

A popular account of the principles involved in the production of talking films and of the apparatus used for projecting them in the cinema, with chapters on theatre acoustics and installation.

The book is profusely illustrated; numerous exclusive and hitherto unpublished diagrams and photographs are reproduced throughout the text. Readers of this book will obtain a thorough insight into inventions and methods of this popular form of entertainment.

SECOND EDITION

Illustrated. **12s. 6d. net.** **324 pp.**

"While it is readily understandable by anyone with a modicum of mechanical or electrical knowledge, it goes sufficiently deeply into the methods and appliances used to be of real value to those engaged in the industry itself."—*Model Engineer.*

"One of the most instructive and complete books on sound films which have so far appeared."—*Kinematograph Weekly.*

"This book is to be thoroughly recommended as an up-to-date non-technical résumé of progress in making and reproducing talking pictures —*Wireless World.*

"The clearest, simplest, and most readable treatise on Talking Pictures which has yet appeared."—*The Bioscope.*

"To those operators and technicians who take their jobs seriously —who want to know the ins and outs of it—this book will prove of great use."—*The Cinema.*

SIR ISAAC PITMAN & SONS, LTD., PARKER STREET, KINGSWAY, W.C.2

AN ABRIDGED LIST OF

TECHNICAL BOOKS

PUBLISHED BY

Sir Isaac Pitman & Sons, Ltd.
Parker Street, Kingsway, London, W.C.2

The prices given apply only to Great Britain

A complete Catalogue giving full details of the following books will be sent post free on application

---

CONTENTS

	PAGE
ART AND CRAFT WORK	2
ARTISTIC CRAFT SERIES	2
ASTRONOMY	10
AVIATION	9, 10
CIVIL ENGINEERING, BUILDING, ETC	7, 8
COMMON COMMODITIES AND INDUSTRIES SERIES	21, 22
DRAUGHTSMANSHIP	4
ELECTRICAL ENGINEERING ETC	11–15
MARINE ENGINEERING	10
MATHEMATICS AND CALCULATIONS FOR ENGINEERS	16, 17
MECHANICAL ENGINEERING	8, 9
METALLURGY AND METAL WORK	5, 6
MINERALOGY AND MINING	6
MISCELLANEOUS TECHNICAL BOOKS	17, 18
MOTOR ENGINEERING	11
OPTICS AND PHOTOGRAPHY	10
PHYSICS, CHEMISTRY, ETC.	4, 5
TECHNICAL PRIMERS	18–20
TELEGRAPHY, TELEPHONY, AND WIRELESS	15, 16
TEXTILE MANUFACTURE ETC	3, 4

C2—10

ALL PRICES ARE NET

THE ARTISTIC CRAFT SERIES

	s.	d.
Bookbinding and the Care of Books. By Douglas Cockerell. Fourth Edition	7	6
Dress Design. By Talbot Hughes	12	6
Embroidery and Tapestry Weaving. By Mrs. A. H. Christie. Fourth Edition	10	6
Hand-Loom Weaving. By Luther Hooper	10	6
Heraldry. By Sir W. H. St. John Hope, Litt.D., D.C.L.	12	6
Silverwork and Jewellery. By H. Wilson. Second Edition	10	6
Stained Glass Work. By C. W. Whall	10	6
Wood-Block Printing. By F. Morley Fletcher	8	6
Woodcarving Design and Workmanship. By George Jack. Second Edition	8	6
Writing and Illuminating and Lettering. By Edward Johnston. Sixteenth Edition	8	6

ART AND CRAFT WORK, ETC.

Block-Cutting and Print-Making by Hand. By Margaret Dobson, A.R.E.	12	6
Cabinet-Making, The Art and Craft of. By D. Denning	5	0
Cellulose Lacquers. By S. Smith, O.B.E., Ph.D.	7	6
Draw Loom, The New. By Luther Hooper	25	0
Handicrafts, Home Decorative. By Mrs. F. Jefferson-Graham	25	0
Lacquer Work. By G. Koizumi	15	0
Leather Work: Stamped, Moulded, Cut, Cuir-Bouilli, Sewn, etc. By Charles G. Leland. Third Edition	5	0
Lettering, Decorative Writing and Arrangement of. By Prof. A. Erdmann and A. A. Braun. Second Edition.	10	6
Lettering and Design, Examples of. By J. Littlejohns, R.B.A.	4	0
Lettering, Plain and Ornamental. By Edwin G. Fooks	3	6
Manuscript and Inscription Letters. By Edward Johnston.	7	6
Manuscript Writing and Lettering. By an Educational Expert	6	0
Metal Work. By Charles G. Leland. Third Edition.	5	0
Plywood and Glue, Manufacture and Use of. By B. C. Boulton, B.Sc.	7	6
Pottery, Handcraft. By H. and D. Wren.	10	6
Stained Glass, The Art and Craft of. By E. W. Twining.	4[illegible]	[illegible]
Stencil-Craft. By Henry Cadness, F.S.A.M.	10	6
Weaving for Beginners. By Luther Hooper	5	0
Weaving with Small Appliances—		
The Weaving Board. By Luther Hooper	7	6
Table Loom Weaving. By Luther Hooper	7	6
Tablet Weaving. By Luther Hooper	7	6
Wood Carving. By Charles G. Leland. Revised by John Holtzapffel. Fifth Edition	[illegible]	[illegible]
Woodcarving, Handicraft of. By James Jackson	4	0

TEXTILE MANUFACTURE, ETC.

	s.	d.
Artificial Silk. By Dr. V. Hottenroth. Translated from the German by Dr. E. Fyleman, B.Sc.	30	0
Artificial Silk. By Dr. O. Faust. Translated by Dr. E. Fyleman	10	6
Artificial Silk and Its Manufacture. By Joseph Foltzer. Translated into English by T. Woodhouse. 4th Ed.	21	0
Artificial Silk or Rayon, Its Manufacture and Uses. By T. Woodhouse, F.T.I. Second Edition	7	6
Artificial Silk or Rayon, The Preparation and Weaving of. By T. Woodhouse, F.T.I.	10	6
Bleaching, Dyeing, Printing, and Finishing for the Manchester Trade. Bv J. W. McMyn, F.C.S., and J. W. Bardsley. Second Edition	6	0
Colour in Woven Design. By Roberts Beaumont, M.Sc., M.I.Mech.E. Second Edition, Revised and Enlarged.	21	0
Cotton Spinner's Pocket Book, The. By James F. Innes. Third Edition	3	6
Cotton Spinning Course, A First Year. By H. A. J. Duncan, A.T.I.	5	0
Cotton World, The. Compiled and Edited by J. A. Todd, M.A., B.L.	5	0
Dress, Blouse, and Costume Cloths. Design and Fabric Manufacture. By Roberts Beaumont, M Sc., M.I.Mech.E., and Walter G. Hill	42	0
Flax and Jute, Spinning, Weaving, and Finishing of. By T. Woodhouse, F.T.I.	10	6
Flax Culture and Preparation. By F. Bradbury. 2nd Ed.	10	6
Fur. By Max Bachrach, B.C.S.	21	0
Furs and Furriery. By Cyril J. Rosenberg	30	0
Hosiery Manufacture. By Prof. W. Davis, M.A. 2nd Ed.	5	0
Knitted Fabrics, Calculations and Costings for. By Professor William Davis, M.A.	10	6
Loom, Theory and Electrical Drive of the. By R. H. Wilmot, M.Sc., A.M.I.E.E., Assoc A.I.E.E.	8	6
Men's Clothing, Organization, Management, and Technology in the Manufacture of. By M. E. Popkin.	25	0
Pattern Construction, The Science of. For Garment Makers. By B. W. Poole	45	0
[illegible] Calculations. By J. H. Whitwam, B.Sc. (Lond.)	25	0
Textile Educator, Pitman's. Edited by L. J. Mills, *Fellow of the Textile Institute*. In three volumes	63	0
Textiles for Salesmen. By E. Ostick, M.A., L.C.P. 2nd Ed.	5	0
Textiles, Introduction to. By A. E. Lewis, A.M.C.T., A.T.I.	3	6
Towels and Towelling, the Design and Manufacture of. By T. Woodhouse, F.T.I., and A. Brand, A.T.I..	12	6
Weaving and Manufacturing, Handbook of. By H. [illegible]nwood, A.T.I..	5	0
Woollen Yarn Production. By T. Lawson	8	6
Wool Substitutes, By Roberts Beaumont, M.Sc., M.I.Mech.E.	10	6

Textile Manufacture, etc.—contd.

	s	d.
Wool, The Marketing of. By A. F. DuPlessis, M.A.	12	6
Worsted Carding and Combing. By J. R. Hind, M.R.S.T., A.T.I.	7	6
Worsted Open Drawing. By S. Kershaw, F.T.I.	5	0
Yarns and Fabrics, The Testing of. By H. P. Curtis. 2nd Ed.	5	0

DRAUGHTSMANSHIP

Blue Print Reading. By J. Brahdy, B Sc., C.E.	10	6
Drawing and Designing. By Charles G. Leland, M.A. Fourth Edition	3	6
Drawing Office Practice. By H. Pilkington Ward, M.Sc., A.M.Inst.C.E.	7	6
Engineer Draughtsmen's Work. By A Practical Draughtsman	2	6
Engineering Design, Examples in. By G. W. Bird, B.Sc. Second Edition	6	0
Engineering Hand Sketching and Scale Drawing. By Thos. Jackson, M.I.Mech.E., and Percy Bentley, A.M.I.Mech.E.	3	0
Engineering Workshop Drawing. By A. C. Parkinson, B.Sc. Second Edition	4	0
Machine Drawing, A Preparatory Course to. By P. W. Scott	2	0
Plan Copying in Black Lines. By B. J. Hall, M.I.Mech.E..	2	6

PHYSICS, CHEMISTRY, ETC.

Artificial Resins. By J. Scheiber, Ph.D. Translated by E. Fyleman, B.Sc., Ph.D., F.I.C.	30	0
Biology, Introduction to Practical. By N. Walker.	5	0
Chemical Engineering, An Introduction to. By A. F. Allen, B.Sc. (Hons.), F.C.S., LL.B.	10	6
Chemistry, A First Book of. By A. Coulthard, B.Sc. (Hons.), Ph.D., F.I.C.	3	0
Chemistry, Definitions and Formulae for Students. By W. G. Carey, F.I.C.	–	6
Chemistry, Test Papers in. By E. J. Holmyard, M.A..	2	0
With Points Essential to Answers	3	0
Chemistry, Higher Test Papers in. By the same Author. 1. Inorganic. 2. Organic. Each	3	0
Dispensing for Pharmaceutical Students. By J. W. Cooper and F. J. Dyer. Second Edition	7	6
Electricity and Magnetism, First Book of. By W. Perren Maycock, M.I.E.E. Fourth Edition.	6	0
Engineering Principles, Elementary. By G. E. Hall, B.Sc.	2	6
Engineering Science, A Primer of. By Ewart S. Andrews, B.Sc. (Eng.).		
II. First Steps in Heat and Heat Engines	2	[illegible]
Latin for Pharmaceutical Students. By J. W. Cooper and A. C. Mclaren	6	0

Physics, Chemistry, etc.—contd.

	s.	d.
Magnetism and Electricity, Higher Test Papers in. By P. J. Lancelot Smith, M.A.	3	0
Magnetism and Electricity, Questions and Solutions in. Solutions by W. J. White, M.I.E.E. Third Edition	5	0
Organic Pigments, Artificial. By Dr. C. A. Curtis. Translated by Ernest Fyleman, B.Sc., Ph.D., F.I.C.	21	0
Pharmaceutical Chemistry, Practical. By J. W. Cooper, Ph.C., and F. N. Appleyard, B.Sc., F.I.C., Ph.C.	5	0
Pharmacognosy, A Textbook of. Part I—Practical. By W. J. Cooper, Ph.C., T. C. Denston, and M. Riley	10	6
Pharmacy, A Course in Practical. By J. W. Cooper, Ph.C., and F. N. Appleyard, B.Sc., F.I.C., Ph.C.	7	6
Pharmacy, General and Official. By J. W. Cooper Ph.C.	10	6
Physical Science, Primary. By W. R. Bower, B.Sc.	5	0
Physics, Experimental. By A. Cowling. With Arithmetical Answers to the Problems	1	9
Physics, Test Papers in. By P. J. Lancelot-Smith, M.A.	2	0
Points Essential to Answers, 4s. In one book	5	6
Volumetric Analysis. By J. B. Coppock, B.Sc. (Lond.), F.I.C F.C.S. Second Edition	3	6
Volumetric Work, A Course of. By E. Clark, B.Sc.	4	6

METALLURGY AND METAL WORK

	s.	d.
Ball and Roller Bearings, Handbook of. By A. W. Macaulay, A.M.I.Mech.E.	7	6
Electroplating. By S. Field and A. Dudley Weill	5	0
Electroplating with Chromium, Copper, and Nickel. By Benjamin Freeman, Ph.D., and Frederick G. Hoppe	21	0
Engineering Materials. Vol. I. Ferrous. By A. W. Judge, Wh.Sc., A.R.C.S.	30	0
Engineering Materials. Vol. II. Non-Ferrous. By A. W. Judge, Wh.Sc., A.R.C.S.	40	0
Engineering Materials. Vol. III. Theory and Testing of Materials. By A. W. Judge, Wh.Sc., A.R.C.S.	21	0
Etching, Metallographers' Handbook of. Compiled by T. Berglund. Translated by W. H. Dearden	12	6
Files and Filing. By Ch. Fremont. Translated into English under the supervision of George Taylor	21	0
Fitting, The Principles of. By J. Horner, A.M.I.M.E. Fifth Edition, Revised and Enlarged	7	6
Foundrywork and Metallurgy. Edited by R. T. Rolfe, F.I.C. In six volumes. Each	6	0
Ironfounding, Practical. By J. Horner, A.M.I.M.E. Fifth Edition, Revised by Walter J. May	10	0
Iron Rolls, The Manufacture of Chilled. By A. Allison	8	6
Joint Wiping and Lead Work. By William Hutton. Third Edition	5	0
Metal Turning. By J. Horner, A M.I.M.E. Fourth Edition,	6	0
Metal Work for Craftsmen. By G. H. Hart, and Golden Keeley, A.M.Inst.B.E., M.Coll.H.	7	6

Metallurgy and Metal Work—contd.

	s.	d.
Metal Work, Practical Sheet and Plate. By E. A. Atkins, A.M.I.M.E. Third Edition, Revised and Enlarged	7	6
Metallurgy, Definitions and Formulae for Students. By R. E. Taylor, A.R.F.M., F.I.C., D.I.C.	–	6
Metallurgy of Bronze. By H. C. Dews	12	6
Metallurgy of Cast Iron. By J. E. Hurst	15	0
Pattern Making, The Principles of. By J. Horner, A.M.I.M.E. Fifth Edition	4	0
Pipe and Tube Bending and Jointing. By S. P. Marks, M.S.I.A.	6	0
Pyrometers. By E. Griffiths, D.Sc.	7	6
Steel Works Analysis. By J. O. Arnold, F.R.S., and F. Ibbotson. Fourth Edition, thoroughly revised	12	6
Welding, Electric. By L. B. Wilson.	5	0
Welding, Electric Arc and Oxy-Acetylene. By E. A. Atkins, A.M.I.M.E.	7	6
Workshop Gauges and Measuring Appliances. By L. Burn, A.M.I.Mech.E., A.M.I.E.E.	5	0

MINERALOGY AND MINING

	s.	d.
Coal Carbonization. By John Roberts, D.I.C., M.I.Min.E., F.G.S.	25	0
Coal Mining, Definitions and Formulae for Students. By M. D. Williams, F.G.S.	–	6
Colliery Electrical Engineering. By G. M. Harvey. Second Edition	15	0
Electrical Engineering for Mining Students. By G. M. Harvey, M.Sc., B.Eng., A.M.I.E.E.	5	0
Electricity Applied to Mining. By H. Cotton, M.B.E., D.Sc., A.M.I.E.E.	35	0
Electric Mining Machinery. By Sydney F. Walker, M.I.E.E., M.I.M.E., A.M.I.C.E., A.Amer.I.E.E.	15	0
Mineralogy. By F. H. Hatch, O.B.E., Ph.D., F.G.S , M.I.C.E. M.I.M.M. Sixth Edition, Revised	6	0
Mining Certificate Series, Pitman's. Edited by John Roberts, D.I.C., M.I.Min.E., F.G.S., Editor of *The Mining Educator*—		
Mining Law and Mine Management. By Alexander Watson, A.R.S.M.	8	6
Mine Ventilation and Lighting. By C. D. Mottram, B.Sc.	8	6
Colliery Explosions and Recovery Work. By J. W. Whitaker, Ph.D. (Eng.), B.Sc., F.I.C., M.I.Min.E..	8	6
Arithmetic and Surveying. By R. M. Evans, B.Sc., F.G.S., M.I.Min.E.	8	6
Mining Machinery. By T. Bryson, A.R.T.C., M.I.Min.E.	12	6
Winning and Working. By Prof. Ira C. F. Statham, B.Eng., F.G.S. M.I.Min.E.	21	0
Mining Educator, The. Edited by J. Roberts, D.I.C., M.I.Min.E., F.G.S. In two vols.	63	0
Mining Science, A Junior Course in. By Henry G. Bishop.	2	6
Tin Mining. By C. G. Moor, M.A.	8	6

CIVIL ENGINEERING, BUILDING, ETC.

	s.	d.
Audel's Masons' and Builders' Guides. In four volumes Each	7	6
1. Brickwork, Brick-laying, Bonding, Designs		
2. Brick Foundations, Arches, Tile Setting, Estimating		
3. Concrete Mixing, Placing Forms, Reinforced Stucco		
4. Plastering, Stone Masonry, Steel Construction, Blue Prints		
Audel's Plumbers' and Steam Fitters' Guides. Practical Handbooks in four volumes . . . . . . Each	7	6
1. Mathematics, Physics, Materials, Tools, Leadwork		
2. Water Supply, Drainage, Rough Work, Tests		
3. Pipe Fitting, Heating, Ventilation, Gas, Steam		
4. Sheet Metal Work, Smithing, Brazing, Motors		
Brickwork, Concrete, and Masonry. Edited by T. Corkhill, M.I.Struct.E. In eight volumes . . . . Each	6	0
"The Builder" Series—		
Architectural Hygiene; or, Sanitary Science as Applied to Buildings. By Sir Banister Fletcher, F.R.I.B.A., F.S.I., and H. Phillips Fletcher, F.R.I.B.A., F.S.I. Fifth Edition, Revised	10	6
Carpentry and Joinery. By Sir Banister Fletcher, F.R.I.B.A., F.S.I., etc, and H. Phillips Fletcher, F.R.I.B.A., F.S.I., etc. Fifth Edition, Revised . .	10	6
Quantities and Quantity Taking. By W. E. Davis. Seventh Edition, Revised by P. T. Walters, F.S.I., F.I.Arb.	6	0
Building, Definitions and Formulae for Students. By T Corkhill, F.B.I.C.C., M.I.Struct.E.	-	6
Building Educator, Pitman's. Edited by R. Greenhalgh, A.I.Struct E. In three volumes	63	0
Building Encyclopaedia, A Concise. Compiled by T. Corkhill, M.I.Struct.E.	7	6
Engineering Equipment of Buildings. By A. C. Pallot, B.Sc. (Eng.)	15	0
Hydraulics. By E. H. Lewitt, B Sc. (Lond.), M.I.Ae.E., A.M.I.M.E. Fourth Edition	10	6
Joinery & Carpentry. Edited by R. Greenhalgh, A.I.Struct.E. In six volumes . . . . Each	6	0
Mechanics of Building. By Arthur D. Turner, A.C.G.I., A.M.I.C.E.	5	0
Painting and Decorating. Edited by C. H. Eaton, F.I.B.D. In six volumes . . . . Each	7	6
Plumbing and Gasfitting. Edited by Percy Manser, R.P., A.R.San.I. In seven volumes . . . . . Each	6	0
Reinforced Concrete, Construction in. By G. P. Manning, M.Eng., A.M.I.C.E.	7	6
Reinforced Concrete, Detail Design in. By Ewart S. Andrews, B.Sc. (Eng.)	6	0

Civil Engineering, Building, etc.—contd.

	s.	d.
Reinforced Concrete. By W. Noble Twelvetrees, M.I.M.E., A.M.I.E.E.	21	0
Reinforced Concrete Members, Simplified Methods of Calculating. By W. Noble Twelvetrees. Second Edition.	5	0
Specifications for Building Works. By W. L. Evershed, F.S.I.	5	0
Structures, The Theory of. By H. W. Coultas, M.Sc., A.M.I.Struct.E., A.I.Mech.E.	15	0
Surveying, Tutorial Land and Mine. By Thomas Bryson	10	6
Water Mains, Lay-out of Small. By H. H. Hellins, M.Inst.C.E.	7	6
Waterworks for Urban and Rural Districts. By H. C. Adams, M.Inst.C.E., M.I.M.E., F.S.I. Second Edition.	15	0

MECHANICAL ENGINEERING

	s.	d.
Audel's Engineers' and Mechanics' Guides. In eight volumes. Vols. 1–7 . Each	7	6
Vol. 8	15	0
Condensing Plant. By R. J. Kaula, M.I.E.E., and I. V. Robinson, Wh.Sc., A.M.Inst.C.E.	30	0
Definitions and Formulae for Students—Applied Mechanics. By E. H. Lewitt, B.Sc., A.M.I.Mech.E..	–	6
Definitions and Formulae for Students—Heat Engines. By A. Rimmer, B.Eng. Second Edition.	–	6
Engineering Educator, Pitman's. Edited by W. J. Kearton, M.Eng., A.M.I.Mech.E., A.M.Inst.N.A. In three volumes	63	0
Engineering Workshop Exercises. By Ernest Pull, A.M.I.Mech.E., M.I.Mar.E. Second Edition, Revised.	3	6
Estimating for Mechanical Engineers. By L. E. Bunnett, A.M.I.P.E.	10	6
Experimental Engineering Science. By Nelson Harwood, B.Sc.	7	6
Friction Clutches. By R. Waring-Brown, A.M.I.A.E., F.R.S.A., M.I.P.E.	5	0
Fuel Economy in Steam Plants. By A. Grounds, B.Sc., F.I.C., F.Inst.P.	5	0
Fuel Oils and Their Applications. By H. V. Mitchell, F.C.S. Second Edition, Revised by A. Grounds, B.Sc., A.I.C.	5	0
Mechanical Engineering Detail Tables. By P. Ross	7	6
Mechanical Engineer's Pocket Book, Whittaker's. Third Edition, entirely rewritten and edited by W. E. Dommett, A.F.Ae.S., A.M.I.A.E.	12	6
Mechanics' and Draughtsmen's Pocket Book. By W. E. Dommett, Wh.Ex., A.M.I.A.E.	2	6
Mechanics for Engineering Students. By G. W. Bird, B.Sc., A.M.I.Mech.E., A.M.I.E.E. Second Edition	5	0
Mechanics of Materials, Experimental. By H. Carrington, M.Sc.(Tech.), D.Sc., M.Inst.Met., A.M.I.Mech.E., A.F.R Ae.S.	3	6

Mechanical Engineering—contd.

	s.	d
Mollier Steam Tables and Diagrams, The. Extended to the Critical Pressure. English Edition adapted and amplified from the Third German Edition by H. Moss, D.Sc., A.R.C.S., D.I.C.	7	6
Mollier Steam Diagrams. Separately in envelope	2	0
Motive Power Engineering. By Henry C. Harris, B.Sc.	10	6
Pulverized Fuel Firing. By Sydney H. North, M.Inst.T.	7	6
Steam Condensing Plant. By John Evans, M.Eng., A.M.I.Mech.E.	7	6
Steam Plant, The Care and Maintenance of. By J. E. Braham, B.Sc, A.C.G.I.	5	0
Steam Turbine Operation. By W. J. Kearton, M.Eng., A.M.I.Mech.E., A.M.Inst.N.A.	12	6
Steam Turbine Theory and Practice. By W. J. Kearton, A.M.I.M.E. Third Edition	15	0
Strength of Materials. By F. V. Warnock, Ph.D., B.Sc. (Lond.), F.R C.Sc.I., A.M.I.Mech.E.	12	6
Theory of Machines. By Louis Toft, M.Sc.Tech., and A. T. J. Kersey, B.Sc. Second Edition	12	6
Thermodynamics, Applied. By Prof. W. Robinson, M.E., M.Inst.C.E.	18	0
Turbo-Blowers and Compressors. By W. J. Kearton, A.M.I M.E.	21	0
Uniflow Back-pressure and Steam Extraction Engines. By Eng. Lieut.-Com. T. Allen, R.N.(S.R.), M.Eng., M.I.Mech.E.	42	0
Workshop Practice. Edited by E. A. Atkins, M.I.Mech.E., M.I.W.E. In eight volumes . Each	6	0

AVIATION

Aero Engines, Light. By C. F. Caunter	12	6
Aerobatics. By Major O. Stewart, M.C., A.F.C.	5	0
Aeronautics, Definitions and Formulae for Students. By J. D. Frier, A.R.C.Sc., D.I.C., F.R.Ae.S.	–	6
Aeroplane Structural Design. By T. H. Jones, B.Sc., A.M.I.M.E., and J. D. Frier, A.R.C.Sc., D.I.C.	21	0
Air and Aviation Law. By W. Marshall Freeman, *Barrister-at-Law*	7	6
Air Navigation for the Private Owner. By Frank A. Swoffer, M.B.E.	7	6
Airmanship. By John McDonough	7	6
Airship, The Rigid. By E. H. Lewitt, B.Sc., M.I.Ae.E.	30	0
Autogiro, C. 19, Book of The. By C. J. Sanders and A. H. Rawson	5	0
Civilian Aircraft, Register of. By W. O. Manning and R. L. Preston	3	6
Flying as a Career. By Major Oliver Stewart, M.C., A.F.C.	3	6

Aviation, etc.—contd.

	s.	d.
Gliding and Motorless Flight. By C. F. Carr and L. Howard-Flanders, A.F.R.Ae.S. Second Edition	7	6
Learning to Fly. By F. A. Swoffer, M.B.E. 2nd Ed.	7	6
Parachutes for Airmen. By Charles Dixon	7	6
Pilot's " A " Licence Compiled by John F. Leeming, *Royal Aero Club Observer for Pilot's Certificates.* Fourth Edition	3	6

MARINE ENGINEERING

	s.	d.
Marine Engineering, Definitions and Formulae for Students. By E. Wood, B.Sc.	–	6
Marine Screw Propellers, Detail Design of. By Douglas H. Jackson, M.I.Mar.E., A.M.I.N.A.	6	0

OPTICS AND PHOTOGRAPHY

	s.	d.
Amateur Cinematography. By Capt. O. Wheeler, F.R.P.S.	6	0
Applied Optics, An Introduction to. Volume I. General and Physiological. By L. C. Martin, D.Sc., D.I.C., A.R.C.S.	21	0
Applied Optics, An Introduction to. Volume II. Theory and Construction of Instruments. By L. C. Martin, D.Sc., A.R.C.S., D.I.C.	21	0
Bromoil and Transfer. By L. G. Gabriel	7	6
Camera Lenses. By A. W. Lockett	2	6
Colour Photography. By Capt. O. Wheeler, F.R.P.S.	12	6
Commercial Photography. By D. Charles	5	0
Complete Press Photographer, The. By Bell R. Bell	6	0
Industrial Microscopy. By Walter Garner, M.Sc.	21	0
Lens Work for Amateurs. By H. Orford. Fifth Edition, Revised by A. Lockett	3	6
Photo-Engraving in Relief. By W. J. Smith, F.R.P.S., E. L. Turner, F.R.P.S., and C. D. Hallam	12	6
Photographic Chemicals and Chemistry. By J. Southworth and T. L. J. Bentley	3	6
Photographic Printing. By R. R. Rawkins	3	6
Photography as a Business. By A. G. Willis	5	0
Photography Theory and Practice. By E. P. Clerc. Edited by G. E. Brown	35	0
Retouching and Finishing for Photographers. By J. S. Adamson. Third Edition	4	0
Studio Portrait Lighting. By H. Lambert, F.R.P.S.	15	0

ASTRONOMY

	s.	d.
Astronomy, Pictorial. By G. F. Chambers, F.R.A.S.	2	6
Astronomy for Everybody. By Professor Simon Newcomb, LL.D. With an Introduction by Sir Robert Ball	5	0
Great Astronomers. By Sir Robert Ball, D.Sc., LL.D., F.R.S.	5	0
High Heavens, In the. By Sir Robert Ball	5	0
Starry Realms, In. By Sir Robert Ball, D.Sc., LL.D., F.R.S.	5	0

MOTOR ENGINEERING

	s.	d.
Automobile and Aircraft Engines By A. W. Judge, A.R.C.S., A.M.I.A.E. Second Edition	42	0
Carburettor Handbook, The. By E. W. Knott, A.M.I.A.E..	10	6
Gas and Oil Engine Operation. By J. Okill, M.I.A.E.. .	5	0
Gas, Oil, and Petrol Engines. By A. Garrard, Wh.Ex. .	6	0
Magneto and Electric Ignition. By W. Hibbert, A.M.I.E.E. Third Edition	3	6
Motor Body Building, Private and Commercial. By H. J. Butler	10	6
Two-Cycle Engine, The. By C. F. Caunter	15	0
Motor-Cyclist's Library, The. Each volume in this series deals with a particular type of motor-cycle from the point of view of the owner-driver . . . . . . Each	2	0
A.J.S., The Book of the. By W. C. Haycraft.		
Ariel, The Book of the. By G. S. Davison.		
B.S.A., The Book of the. By "Waysider."		
Douglas, The Book of the. By E. W. Knott.		
Matchless, The Book of the. By W. C. Haycraft.		
New Imperial, The Book of the. By F. J. Camm.		
Norton, The Book of the. By W. C. Haycraft		
P. and M., The Book of the. By W. C. Haycraft.		
Raleigh Handbook, The. By "Mentor."		
Royal Enfield, The Book of the. By R. E. Ryder.		
Rudge, The Book of the. By L. H. Cade.		
Sunbeam, The Book of the. By L. K. Heathcote.		
Triumph, The Book of the. By E. T. Brown.		
Villiers Engine, Book of the. By C. Grange.		
Motorists' Library, The. Each volume in this series deals with a particular make of motor-car from the point of view of the owner-driver.		
Austin, The Book of the. By B. Garbutt. Third Edition, Revised by E. H. Row	3	6
Morgan, The Book of the. By G. T. Walton . .	2	6
Singer Junior, Book of the. By G. S. Davison. .	2	6
Standard Nine, The Book of the. By John Speedwell	2	6
Motorist's Electrical Guide, The. By A. H. Avery, A.M.I.E.E.	3	6
Caravanning and Camping. By A. H. M. Ward, M.A.	2	6

ELECTRICAL ENGINEERING, ETC.

	s.	d.
Acoustical Engineering. By W. West, B.A. (Oxon), A.M.I.E.E.	15	0
Accumulator Charging, Maintenance, and Repair. By W. S. Ibbetson. Second Edition	3	6
Alternating Current Bridge Methods. By B. Hague, D.Sc. Second Edition	15	0

Electrical Engineering, etc.—contd.

	s.	*d.*
Alternating Current Circuit. By Philip Kemp, M.I.E.E..	2	6
Alternating Current Machinery, Papers on the Design of. By C. C. Hawkins, M.A., M.I.E.E., S. P. Smith, D.Sc., M.I.E.E., and S. Neville, B.Sc.	21	0
Alternating Current Power Measurement. By G. F. Tagg, B.Sc.	3	6
Alternating Current Work. By W. Perren Maycock, M.I.E.E. Second Edition	10	6
Alternating Currents, The Theory and Practice of. By A. T. Dover, M.I.E.E. Second Edition	18	0
Armature Winding, Practical Direct Current. By L. Wollison	7	6
Cables, High Voltage. By P. Dunsheath, O.B.E., M.A., B.Sc., M.I.E.E.	10	6
Continuous Current Dynamo Design, Elementary Principles of. By H. M. Hobart, M.I.C.E., M.I.M.E., M.A.I.E.E.	10	6
Continuous Current Motors and Control Apparatus. By W. Perren Maycock, M.I.E.E..	7	6
Definitions and Formulae for Students—Electrical. By P. Kemp, M.Sc., M.I.E.E.	–	6
Definitions and Formulae for Students—Electrical Installation Work. By F. Peake Sexton, A.R.C.S., A.M.I.E.E.	–	6
Direct Current Electrical Engineering, Elements of. By H. F. Trewman, M.A., and C. E. Condliffe, B.Sc.. .	5	0
Direct Current Electrical Engineering, Principles of. By James R. Barr, A.M.I.E.E.	15	0
Direct Current Dynamo and Motor Faults. By R. M. Archer	7	6
Direct Current Machines, Performance and Design of. By A. E. Clayton, D.Sc., M.I.E.E.	16	0
Dynamo, The: Its Theory, Design, and Manufacture. By C. C. Hawkins, M.A., M.I.E.E. In three volumes. Sixth Edition—		
Volume I	21	0
II	15	0
III	30	0
Dynamo, How to Manage the. By A. E. Bottone. Sixth Edition, Revised and Enlarged	2	0
Electric and Magnetic Circuits, The Alternating and Direct Current. By E. N. Pink B.Sc., A.M.I.E.E. .	3	6
Electric Bells and All About Them. By S. R. Bottone. Eighth Edition, thoroughly revised by C. Sylvester, A.M.I.E.E.	3	6

Electrical Engineering, etc.—contd.

	s.	d.
Electric Circuit Theory and Calculations. By W. Perren Maycock, M.I.E.E. Third Edition, Revised by Philip Kemp, M.Sc., M.I.E.E., A.A.I.E.E.	10	6
Electric Light Fitting, Practical. By F. C. Allsop. Tenth Edition, Revised and Enlarged	7	6
Electric Lighting and Power Distribution. By W. Perren Maycock, M.I.E.E. Ninth Edition, thoroughly Revised by C. H. Yeaman In two volumes . Each	10	6
Electric Machines, Theory and Design of. By F. Creedy, M.A.I.E.E., A.C.G.I.	30	0
Electric Motors and Control Systems. By A. T. Dover, M.I.E.E., A.Amer.I.E.E.	15	0
Electric Motors (Direct Current): Their Theory and Construction. By H. M. Hobart, M.I.E.E., M.Inst.C.E., M.Amer.I.E.E. Third Edition, thoroughly Revised	15	0
Electric Motors for Continuous and Alternating Currents, A Small Book on. By W. Perren Maycock, M.I.E.E.	6	0
Electric Traction. By A. T. Dover, M.I.E.E., Assoc.Amer. I.E.E. Second Edition	25	0
Electric Train-Lighting. By C. Coppock	7	6
Electric Trolley Bus. By R. A. Bishop	12	6
Electric Wiring Diagrams. By W. Perren Maycock, M.I.E.E.	5	0
Electric Wiring, Fittings, Switches, and Lamps. By W. Perren Maycock, M.I.E.E. Sixth Edition. Revised by Philip Kemp, M.Sc., M.I.E.E.	10	6
Electric Wiring of Buildings. By F. C. Raphael, M.I.E.E.	10	6
Electric Wiring Tables. By W. Perren Maycock, M.I.E.E. Revised by F. C. Raphael, M.I.E.E. Sixth Edition	3	6
Electrical Condensers. By Philip R. Coursey, B.Sc., F.Inst.P., A.M.I.E.E.	37	6
Electrical Educator. By Sir Ambrose Fleming, M A., D.Sc., F R S. In three volumes. Second Edition	72	0
Electrical Engineering, Classified Examples in. By S. Gordon Monk, B.Sc. (Eng.), A.M.I.E E. In two parts—		
Volume I. Direct Current. Second Edition.	2	6
II. Alternating Current. Second Edition	3	6
Electrical Engineering, Elementary. By O. R. Randall, Ph.D., B.Sc., Wh.Ex.	5	0
Electrical Engineering, Experimental. By E. T. A. Rapson, A.C.G.I., D.I.C., A.M.I.E.E.	3	6
Electrical Engineer's Pocket Book, Whittaker's. Originated by Kenelm Edgcumbe, M.I.E.E., A.M.I.C.E. Sixth Edition. Edited by R. E. Neale, B.Sc. (Hons.)	10	6
Electrical Instrument Making for Amateurs. By S. R. Bottone. Ninth Edition.	6	0
Electrical Insulating Materials. By A. Monkhouse, Junr., M.I.E.E., A.M.I.Mech.E.	21	0

Electrical Engineering, etc.—contd.

	s.	d.
ELECTRICAL GUIDES, HAWKINS'. Each book in pocket size .	5	0
1. ELECTRICITY, MAGNETISM, INDUCTION, EXPERIMENTS, DYNAMOS, ARMATURES, WINDINGS		
2. MANAGEMENT OF DYNAMOS, MOTORS, INSTRUMENTS, TESTING		
3. WIRING AND DISTRIBUTION SYSTEMS, STORAGE BATTERIES		
4. ALTERNATING CURRENTS AND ALTERNATORS		
5. A.C. MOTORS, TRANSFORMERS, CONVERTERS, RECTIFIERS		
6. A.C. SYSTEMS, CIRCUIT BREAKERS, MEASURING INSTRUMENTS		
7. A.C. WIRING, POWER STATIONS, TELEPHONE WORK		
8. TELEGRAPH, WIRELESS, BELLS, LIGHTING		
9. RAILWAYS, MOTION PICTURES, AUTOMOBILES, IGNITION		
10. MODERN APPLICATIONS OF ELECTRICITY. REFERENCE INDEX		
ELECTRICAL MACHINERY AND APPARATUS MANUFACTURE. Edited by Philip Kemp, M.Sc., M.I.E.E., Assoc.A.I.E.E. In seven volumes . . . . Each	6	0
ELECTRICAL MACHINES, PRACTICAL TESTING OF. By L. Oulton, A.M.I.E.E., and N. J. Wilson, M.I.E.E. Second Edition .	6	0
ELECTRICAL MEASURING INSTRUMENTS, COMMERCIAL. By R. M. Archer, B.Sc. (Lond.), A.R.C.Sc., M.I.E.E.	10	6
ELECTRICAL POWER TRANSMISSION AND INTERCONNECTION. By C. Dannatt, B.Sc., and J. W. Dalgleish, B.Sc. . . .	30	0
ELECTRICAL TECHNOLOGY. By H. Cotton, M.B.E., D.Sc. .	12	6
ELECTRICAL TERMS, A DICTIONARY OF. By S. R. Roget, M.A., A.M.Inst.C.E., A.M.I.E.E. Second Edition	7	6
ELECTRICAL TRANSMISSION AND DISTRIBUTION. Edited by R. O. Kapp, B.Sc. In eight volumes. Vols. I to VII, Each	6	0
Vol. VIII	3	0
ELECTRICAL WIRING AND CONTRACTING. Edited by H. Marryat, M.I.E.E., M.I.Mech.E. In seven volumes . Each	6	0
ELECTRO-TECHNICS, ELEMENTS OF. By A. P. Young, O.B.E., M.I.E.E.	5	0
FRACTIONAL HORSE-POWER MOTORS. By A. H. Avery, A.M.I.E.E.	7	6
INDUCTION COIL, THE THEORY OF THE. By E. Taylor-Jones, D.Sc., F.Inst.P.	12	6
INDUCTION MOTOR PRACTICE. By R. E. Hopkins, B.Sc., A.M.I.E.E., D.I.C., A.C.C.I.	15	0
INDUCTION MOTOR, THE. By H. Vickers, Ph.D., M.Eng. .	21	0
KINEMATOGRAPHY PROJECTION: A GUIDE TO. By Colin H. Bennett, F.C.S., F.R.P.S.	10	6
MERCURY-ARC RECTIFIERS AND MERCURY-VAPOUR LAMPS. By Sir Ambrose Fleming, M.A., D.Sc., F.R.S.	6	0
METER ENGINEERING. By J. L. Ferns, B.Sc. (Hons.), A.M.C.T.	10	6
OSCILLOGRAPHS. By J. T. Irwin, A.M.I.E.E. . . .	7	6

Electrical Engineering, etc.—contd.

	s.	*d.*
Power Distribution and Electric Traction, Examples in. By A. T. Dover, M.I.E.E., A.A.I.E.E.	3	6
Power Station Efficiency Control. By John Bruce, A.M.I.E.E.	12	6
Power Wiring Diagrams. By A. T. Dover, M.I.E.E., A.Amer. I.E.E. Second Edition, Revised	6	0
Practical Primary Cells. By A. Mortimer Codd, F.Ph.S.	5	0
Railway Electrification. By H. F. Trewman, A.M.I.E.E.	21	0
Sags and Tensions in Overhead Lines. By C. G. Watson, M.I.E.E.	12	6
Steam Turbo-Alternator, The. By L. C. Grant, A.M.I.E.E.	15	0
Storage Batteries: Theory, Manufacture, Care, and Application. By M. Arendt, E.E.	18	0
Storage Battery Practice. By R. Rankin, B.Sc., M.I.E.E.	7	6
Switchgear Design, Elements of. By Dr. Mg. Fritz Kesselring, translated by S. R. Mellonie, A.M.I.E.E., Assoc. A.I.E.E., and J. Solomon, B.Sc. (Eng.), A.M.I.E.E.	7	6
Transformers for Single and Multiphase Currents. By Dr. Gisbert Kapp, M Inst.C.E., M.I.E.E. Third Edition, Revised by R. O. Kapp, B.Sc.	15	0

TELEGRAPHY, TELEPHONY, AND WIRELESS

	s.	*d.*
Automatic Branch Exchanges, Private. By R. T. A. Dennison	12	6
Automatic Telephony, Relays in. By R. W. Palmer, A.M.I.E.E.	10	6
Baudôt Printing Telegraph System. By H. W. Pendry. Second Edition	6	0
Cable and Wireless Communications of the World, The. By F. J. Brown, C.B., C.B.E., M.A., B.Sc. (Lond.). Second Edition	7	6
Radio Communication, Modern. By J. H. Reyner, B.Sc. (Hons.), A.C.G.I., D.I.C. Fourth Edition	5	0
Submarine Telegraphy. By Ing. Italo de Giuli. Translated by J. J. McKichan, O.B.E., A.M.I.E.E.	18	0
Telegraphy. By T. E. Herbert, M.I.E.E. Fifth Edition	20	0
Telegraphy, Elementary. By H. W. Pendry. Second Edition, Revised	7	6
Telephone Handbook and Guide to the Telephonic Exchange, Practical. By Joseph Poole, A.M.I.E.E. (Wh.Sc.). Seventh Edition	18	0
Telephony. Vol. I. Manual Switching Systems and Line Plant. By T. E. Herbert, M.I.E.E.	20	0
Telephony Simplified, Automatic. By C. W. Brown, A.M.I.E.E., *Engineer-in-Chief's Department, G.P.O., London*	6	0
Telephony, The Call Indicator System in Automatic. By A. G. Freestone, *of the Automatic Training School, G.P.O., London*	6	0

Telegraphy, Telephony, and Wireless—contd.

	s.	d.
Telephony, The Director System of Automatic. By W. E. Hudson, B.Sc. Hons. (London), Whit.Sch., A.C.G.I.	5	0
Television : To-day and To-morrow. By Sydney A. Moseley and H J. Barton Chapple, Wh.Sc., B.Sc. (Hons.), A.C.G.I., D.I.C., A.M.I.E.E. Second Edition	7	6
Photoelectric Cells. By Dr. N. I. Campbell and Dorothy Ritchie. Second Edition.	15	0
Wireless Manual, The. By Capt. J. Frost, I.A. (Retired), Revised by H. V. Gibbons. Third Edition	5	0
Wireless Telegraphy and Telephony, Introduction to. By Sir Ambrose Fleming, M.A., D.Sc., F.R.S.	3	6

MATHEMATICS AND CALCULATIONS FOR ENGINEERS

	s.	d.
Alternating Currents, Arithmetic of. By E. H. Crapper, D.Sc. M.I.E.E.	4	6
Calculus for Engineering Students. By John Stoney, B.Sc., A.M.I.Min.E.	3	6
Definitions and Formulae for Students—Practical Mathematics. By L. Toft, M.Sc.	–	6
Electrical Engineering, Whittaker's Arithmetic of. Third Edition, Revised and Enlarged	3	6
Exponential and Hyberbolic Functions. By A. H. Bell, B.Sc.	3	6
Geometry, Building. By Richard Greenhalgh, A.I.Struct.E.	4	6
Geometry, Contour. By A. H. Jameson, M.Sc., M.Inst.C.E.	7	6
Geometry, Exercises in Building. By Wilfred Chew	1	6
Graphic Statics, Elementary. By J. T. Wight, A.M.I.Mech.E.	5	0
Kilograms into Avoirdupois, Table for the Conversion of. Compiled by Redvers Elder. On paper	1	0
Logarithms for Beginners. By C. N. Pickworth, Wh.Sc. Eighth Edition	1	6
Logarithms, Five Figure, and Trigonometrical Functions. By W. E. Dommett, A.M.I.A.E., and H C Hird, A.F.Ae.S.	1	0
Logarithms Simplified. By Ernest Card, B.Sc., and A. C Parkinson, A.C.P. Second Edition	2	0
Mathematics and Drawing, Practical. By Dalton Grange.	2	0
With Answers	2	6
Mathematics, Engineering, Application of. By W. C. Bickley, M.Sc.	5	0
Mathematics, Experimental. By G R. Vine, B.Sc. Book I, with Answers	1	4
II, with Answers	1	4
Mathematics for Engineers, Preliminary. By W. S. Ibbetson, B.Sc., A.M.I.E.E , M.I.Mar.E.	3	6
Mathematics, Practical. By Louis Toft, M.Sc. (Tech.), and A. D. D. McKay, M.A.	16	0
Mathematics for Technical Students. By G. E Hall, B.Sc.	5	0

Mathematics for Engineers—contd.

	s.	d.
Mathematics, Industrial (Preliminary), By G. W. Stringfellow	2	0
With Answers	2	6
Measuring and Manuring Land, and Thatcher's Work, Tables for. By J. Cullyer. Twentieth Impression	3	0
Mechanical Tables. By J. Foden	2	0
Mechanical Engineering Detail Tables. By John P. Ross	7	6
Metalworker's Practical Calculator, The. By J. Matheson	2	0
Metric Conversion Tables. By W. E. Dommett, A.M.I.A.E.	1	0
Metric Lengths to Feet and Inches, Table for the Conversion of. Compiled by Redvers Elder. On paper.	1	0
Mining Mathematics (Preliminary). By George W. Stringfellow	1	6
With Answers	2	0
Nomogram, The. By H. J. Allcock, B.Sc., A.M I.E.E., A.M.I Mech.E., and J. R. Jones, M.A., F.G.S.	10	6
Quantities and Quantity Taking. By W. E. Davis. Seventh Edition, Revised by P. T. Walters, F.S.I., F.I.Arb.	6	0
Science and Mathematical Tables. By W. F. F. Shearcroft, B.Sc., A.I.C., and Denham Larrett, M.A.	1	0
Slide Rule, The. By C. N. Pickworth, Wh.Sc. Seventeenth Edition, Revised	3	6
Slide Rule: Its Operations; and Digit Rules, The. By A. Lovat Higgins, A.M.Inst.C.E.	–	6
Steel's Tables. Compiled by Joseph Steel	3	6
Telegraphy and Telephony, Arithmetic of. By T. E. Herbert, M.I.E.E., and R. G. de Wardt	5	0
Trigonometry for Engineers, A Primer of. By W. G. Dunkley, B.Sc. (Hons.)	5	0
Trigonometry for Navigating Officers. By W. Percy Winter, B.Sc. (Hons.), Lond.	10	6
Trigonometry, Practical. By Henry Adams, M.I.C.E., M.I.M.E., F.S.I. Third Edition, Revised and Enlarged	5	0
Ventilation, Pumping, and Haulage, Mathematics of. By F. Birks	5	0
Workshop Arithmetic, First Steps in. By H. P. Green	1	0

MISCELLANEOUS TECHNICAL BOOKS

	s.	d.
Boot and Shoe Manufacture. By F. Plucknett	35	0
Bowls, The Modern Technique of. By H. P. Webber and Dr. J. W. Fisher	7	6
Brewing and Malting. By J. Ross Mackenzie, F.C.S., F.R.M.S. Second Edition	8	6
Builder's Business Management. By J. H. Bennetts, A.I.O.B.	10	6
Ceramic Industries Pocket Book. By A. B. Searle	8	6
Cinema Organ, The. By Reginald Foort, F.R.C.O.	2	6

Miscellaneous Technical Books—contd.

	s.	d.
Cost Accounts in Rubber and Plastic Trades. By T. W. Fazakerley	5	0
Delphinium, The Book of the. By J. F. Leeming	3	6
Electrical Housecraft. By R. W. Kennedy	2	6
Engineering Economics. By T. H. Burnham, B.Sc. (Hons.), B.Com., A.M.I.Mech.E. Second Edition	10	6
Engineering Inquiries, Data for. By J. C. Connan, B.Sc., A.M.I.E.E., O.B.E.	12	6
Faraday, Michael, and Some of His Contemporaries. By Prof. William Cramp, D.Sc., M.I.E.E.	2	6
Furniture Styles. By. H. E. Binstead. Second Edition	10	6
Glue and Gelatine. By P. I. Smith	8	6
Gramophone Handbook. By W. S. Rogers	2	6
Hairdressing, The Art and Craft of. Edited by G. A. Foan.	60	0
Hiker and Camper, The Complete. By C. F. Carr	2	6
House Decorating, Practical. By Millicent Vince	3	6
House Decorations and Repairs. By W. Prebble. 2nd Ed.	1	0
Motor Boating. By F. H. Snoxell	2	6
Paper Testing and Chemistry for Printers. By Gordon A. Jahans, B.A.	12	6
Petroleum. By Albert Lidgett. Third Edition	5	0
Plan Drawing for the Police. By James D. Cape, P.A.S.I.	2	0
Printing. By H. A. Maddox	5	0
Refractories for Furnaces, Crucibles, etc. By A. B. Searle	5	0
Refrigeration, Mechanical. By Hal Williams, M.I.Mech.E., M.I.E.E., M.I.Struct.E. Third Edition	20	0
Seed Testing. By J. Stewart Remington	10	6
Shoe Repairer's Handbooks. By D. Laurence-Lord. In seven volumes. Vols. 5–7 (In preparation) . . Each	3	6
Stones, Precious and Semi-Precious. By Michael Weinstein. Second Edition	7	6
Talking Pictures. By Bernard Brown, B.Sc. (Eng.). Second Edition	12	6
Teaching Methods for Technical Teachers. By J. H. Currie, M.A., B.Sc., A.M.I.Mech.E.	2	6

PITMAN'S TECHNICAL PRIMERS

	s.	d.
Each in foolscap 8vo, cloth, about 120 pp., illustrated	2	6

The Technical Primer Series is intended to enable the reader to obtain an introduction to whatever technical subject he desires.

Abrasive Materials. By A. B. Searle.

A.C. Protective Systems and Gears. By J. Henderson, B.Sc., M.C., and C. W. Marshall, B.Sc., M.I.E.E.

Belts for Power Transmission. By W. G. Dunkley, B.Sc.

Boiler Inspection and Maintenance. By R. Clayton.

Capstan and Automatic Lathes. By Philip Gates.

Central Stations, Modern. By C. W. Marshall, B.Sc., A.M.I.E.E.

Pitman's Technical Primers—contd. Each 2s. 6d.

Coal Cutting Machinery, Longwall. By G. F. F. Eagar, M.I.Min.E.
Continuous Current Armature Winding. By F. M. Denton, A.C.G.I., A.Amer.I.E.E.
Continuous Current Machines, The Testing of. By Charles F. Smith, D.Sc., M.I.E.E., A.M.I.C.E.
Cotton Spinning Machinery and Its Uses. By Wm. Scott Taggart, M.I.Mech.E.
Diesel Engine, The. By A. Orton, A.M.I.Mech.E.
Drop Forging and Drop Stamping. By H. Hayes.
Electric Cables. By F. W. Main, A.M.I.E.E.
Electric Cranes and Hauling Machines By F. E. Chilton, A.M.I.E.E.
Electric Furnace, The. By Frank J. Moffett, B.A., M.I.E.E.
Electric Motors, Small. By E. T. Painton, B.Sc., A.M.I.E.E.
Electrical Insulation. By W. S. Flight, A.M.I.E.E.
Electrical Transmission of Energy. By W. M. Thornton, O.B.E., D.Sc., M.I.E.E.
Electricity in Agriculture. By A. H. Allen, M.I.E.E.
Electricity in Steel Works. By Wm. McFarlane, B.Sc.
Electrification of Railways, The. By H. F. Trewman, M A.
Electro-Deposition of Copper, The. And its Industrial Applications. By Claude W. Denny, A.M.I.E.E.
Explosives, Manufacture and Uses of. By R. C. Farmer, O.B.E., D.Sc., Ph.D.
Filtration. By T. R. Wollaston, M.I.Mech.E.
Foundrywork. By Ben Shaw and James Edgar.
Grinding Machines and Their Uses. By Thos. R. Shaw, M.I.Mech.E.
Hydro-Electric Development. By J. W. Meares, F.R.A.S., M.Inst.C.E., M.I.E.E., M.Am.I.E.E.
Illuminating Engineering, The Elements of. By A. P. Trotter, M.I.E.E.
Industrial and Power Alcohol. By R. C. Farmer, O.B.E., D.Sc., Ph.D., F.I.C.
Industrial Motor Control. By A. T. Dover, M.I.E.E.
Industrial Nitrogen. By P. H. S. Kempton, B.Sc. (Hons.), A.R.C.Sc.
Kinematograph Studio Technique. By L. C. Macbean.
Lubricants and Lubrication. By J. H. Hyde.
Mechanical Handling of Goods, The. By C. H. Woodfield, M.I.Mech.E.
Mechanical Stoking. By D. Brownlie, B.Sc., A.M.I.M.E. (Double volume, price 5s. net.)
Metallurgy of Iron and Steel. Based on Notes by Sir Robert Hadfield.
Municipal Engineering. By H. Percy Boulnois, M.Inst.C.E., F.R.San.Inst., F.Inst.S.E.

Pitman's Technical Primers—contd. Each 2*s*. 6*d*

Oils, Pigments, Paints, and Varnishes. By R. H. Truelove.

Patternmaking. By Ben Shaw and James Edgar.

Petrol Cars and Lorries. By F. Heap.

Photographic Technique. By L. J. Hibbert, F.R.P.S.

Pneumatic Conveying. By E. G. Phillips, M.I.E.E., A.M.I.Mech.E.

Power Factor Correction. By A. E. Clayton, B.Sc. (Eng.) Lond., A.K.C., A.M.I.E.E.

Radioactivity and Radioactive Substances. By J. Chadwick, M.Sc., Ph.D.

Railway Signalling: Automatic. By F. Raynar Wilson.

Railway Signalling: Mechanical. By F. Raynar Wilson.

Sewers and Sewerage. By H. Gilbert Whyatt, M.I.C.E.

Sparking Plugs. By A. P. Young and H. Warren.

Steam Engine Valves and Valve Gears. By E. L. Ahrons, M.I.Mech.E., M.I.Loco.E.

Steam Locomotive, The. By E. L. Ahrons, M.I.Mech.E., M.I.Loco.E.

Steam Locomotive Construction and Maintenance. By E. L. Ahrons, M.I.Mech.E., M.I.Loco.E.

Steelwork, Structural. By Wm. H. Black.

Streets, Roads, and Pavements. By H. Gilbert Whyatt, M.Inst.C.E., M.R.San.I.

Switchboards, High Tension. By Henry E. Poole, B.Sc. (Hons.), Lond., A.C.G.I., A.M.I.E.E.

Switchgear, High Tension. By Henry E. Poole, B.Sc.(Hons.), A.C.G.I., A.M.I.E.E.

Switching and Switchgear. By Henry E. Poole, B.Sc.(Hons.), A.C.G.I., A.M.I.E.E.

Telephones, Automatic. By F. A. Ellson, B.Sc., A.M.I.E.E. (Double volume, price 5s.)

Tidal Power. By A. M. A. Struben, O.B.E., A.M.Inst.C.E.

Tool and Machine Setting. For Milling, Drilling, Tapping, Boring, Grinding, and Press Work. By Philip Gates.

Town Gas Manufacture. By Ralph Staley, M.C.

Traction Motor Control. By A. T. Dover, M.I.E.E.

Transformers and Alternating Current Machines, The Testing of. By Charles F. Smith, D.Sc., A.M.Inst.C.E.

Transformers, High Voltage Power. By Wm. T. Taylor, M.Inst.C.E., M.I.E.E.

Transformers, Small Single-Phase. By Edgar T. Painton, B.Sc. Eng. (Hons.) Lond., A.M.I.E.E.

Water Power Engineering. By F. F. Fergusson, C.E., F.G.S., F.R.G.S.

Wireless Telegraphy, Continuous Wave. By B. E. G. Mittell, A.M.I.E.E.

Wireless Telegraphy, Directive. Direction and Position Finding, etc. By L. H. Walter, M.A. (Cantab.), A.M.I.E.E.

X-Rays, Industrial Application of. By P. H. S. Kempton, B.Sc. (Hons.), A.R.C.S.

COMMON COMMODITIES AND INDUSTRIES

Each book in crown 8vo, illustrated. 3s. net.

In each of the handbooks in this series a particular product or industry is treated by an expert writer and practical man of business. Beginning with the life history of the plant, or other natural product, he follows its development until it becomes a commercial commodity, and so on through the various phases of its sale in the market and its purchase by the consumer.

Asbestos. (Summers.)

Bookbinding Craft and Industry. (Harrison.)

Books—From the MS. to the Bookseller. (Young.)

Boot and Shoe Industry, The. (Harding.)

Bread and Bread Baking. (Stewart.)

Brushmaker, The. (Kiddier.)

Butter and Cheese. (Tisdale and Jones.)

Button Industry, The. (Jones.)

Carpets. (Brinton.)

Clays and Clay Products. (Searle.)

Clocks and Watches. (Overton.)

Clothing Industry, The. (Poole.)

Cloths and the Cloth Trade. (Hunter.)

Coal. (Wilson.)

Coal Tar. (Warnes.)

Coffee—From Grower to Consumer. (Keable.)

Cold Storage and Ice Making. (Springett.)

Concrete and Reinforced Concrete. (Twelvetrees.)

Copper—From the Ore to the Metal. (Picard.)

Cordage and Cordage Hemp and Fibres. (Woodhouse and Kilgour.)

Corn Trade, The British. (Barker.)

Cotton. (Peake.)

Cotton Spinning. (Wade.)

Drugs in Commerce. (Humphrey.)

Dyes. (Hall.)

Engraving. (Lascelles.)

Explosives, Modern. (Levy.)

Fertilizers. (Cave.)

Fishing Industry, The. (Gibbs.)

Furniture. (Binstead.)

Furs and the Fur Trade. (Sachs.)

Gas and Gas Making. (Webber.)

Glass and Glass Making. (Marson.)

Gloves and the Glove Trade. (Ellis.)

Gold. (White.)

Gums and Resins. (Parry.)

Iron and Steel. (Hood.)

Ironfounding. (Whiteley.)

Jute Industry The. (Woodhouse and Kilgour.)

Knitted Fabrics. (Chamberlain and Quilter.)

Lead, including Lead Pigments. (Smythe.)

Leather. (Adcock.)

Linen. (Moore.)

Locks and Lock Making. (Butter.)

Match Industry, The. (Dixon.)

Meat Industry The. (Wood.)

Oils. (Mitchell.)

Paints and Varnishes. (Jennings.)

Paper. (Maddox.)

Perfumery, The Raw Materials of. (Parry.)

Photography. (Gamble.)

Platinum Metals, The. (Smith.)

Pottery. (Noke and Plant.)

Common Commodities and Industries—contd.

Rice. (Douglas.)
Rubber. (Stevens and Stevens.)
Salt. (Calvert.)
Silk. (Hooper.)
Soap. (Simmons.)
Sponges. (Cresswell.)
Starch and Starch Products. (Auden.)
Stones and Quarries. (Howe.)
Sugar. (Martineau.) (Revised by Eastick.)
Sulphur and Allied Products. (Auden.)
Tea. (Ibbetson.)
Telegraphy, Telephony, and Wireless. (Poole.)
Textile Bleaching. (Steven.)
Timber. (Bullock.)
Tin and the Tin Industry. (Mundey.)
Tobacco. (Tanner.) (Revised by Drew.)
Weaving. (Crankshaw.)
Wheat and Its Products. (Millar.)
Wine and the Wine Trade. (Simon.)
Wool. (Hunter.)
Worsted Industry, The. (Dumville and Kershaw.)
Zinc and Its Alloys. (Lones.)

PITMAN'S SHORTHAND
INVALUABLE TO ALL BUSINESS AND PROFESSIONAL MEN

The following Catalogues will be sent post free on application—

Scientific and Technical
Educational, Commercial, Shorthand
Foreign Languages, and Art

PRINTED IN GREAT BRITAIN AT THE PITMAN PRESS, BATH
(4367W) 0/32